COMPARISON OF ORTHOGONAL TRANSFORMS FOR TELESEISMIC DATA

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The availability of fast algorithms for computing the orthogonal transforms such as the fast Fourier transform (FFT), Walsh-Hadamard transform (WHT), discrete Chebyshev transform (DCT), and related transforms has made such transforms increasingly popular in data processing. This paper is concerned with the comparative evaluation of these transforms as applied to the ACDA teleseismic data. Computer results and program listings are provided. The paper is concluded with the recommendation that better orthogonal transforms are needed for both signal processing and seismic discrimination.

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COMPARISON OF ORTHOGONAL TRANSFORMS FOR TELESEISMIC DATA

by

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North Dartmouth, Massachusetts 02747

Abstract

The availability of fast algorithms for computing the orthogonal transforms such as the fast Fourier transform (FFT), Walsh-Hadamard transform (WHT), discrete Chebyshev transform (DCT), and related transforms has made such transforms increasingly popular in data processing. This paper is concerned with the comparative evaluation of these transforms as applied to the ACDA teleseismic data. Computer results and program listings are provided. The paper is concluded with the recommendation that better orthogonal transforms are needed for both signal processing and seismic discrimination.

Comparison of Orthogonal Transforms for Teleseismic Data

C. H. Chen

I. Introduction

In recent years there has been an increasing interest with respect to using a class of orthogonal transforms in the areas of pattern recognition and digital signal processing. In pattern recognition, orthogonal transforms enable a noninvertible transformation from the pattern space to a reduced dimensionality feature space. This allows a classification scheme to be implemented with substantially less features, with only a small increase in classification error. In digital processing, orthogonal transforms implemented by fast algorithms are basic operations for digital filtering, spectral estimation, etc. In discrete (Wiener) filtering for signal parameter estimation, orthogonal transforms "compress" the useful data to a substantially small number of elements and thus simplifies the filter structure and reduces the computation load. Orthogonal transforms are also useful in designing multiplexing communication systems.

The Walsh-Hadamard transform, discrete Fourier transform, the Haar transform, the slant transform, and discrete Chebyshev transform (also called discrete cosine transform) have been considered for various applications, since these are orthogonal transforms that can be computed using fast algorithms. The Karhunen-Loeve transform (KLT) is an orthogonal transform which is optimal in the minimum mean squared error sense; but is computationally difficult . In this paper we are concerned with the comparative evaluation of these orthogonal transforms for teleseismic data study including signal processing and seismic discrimination (pattern recognition).

II. The Orthogonal Transforms

Of all the orthogonal transforms presently available, the discrete Fourier transform is probably the most conveniently available and provides the most familiar frequency domain informations on the seismic data. The fast Fourier transform also serves as

the groundwork for all transforms with sinusoidal basis functions such as the discrete Chebyshev transform and nonrecursive digital filtering. The phase spectrum which is often ignored contains much useful information. To utilize both amplitude and phase spectra in the Fourier domain is not a simple task. The homomorphic deconvolution or the complex cepstrum accomplishes this objective by taking the logarithm of the complex Fourier spectrum. The problem with the cepstral approach is that it is difficult to obtain accurate long pass and short pass system outputs especially with the noisy data. The teleseismic data is highly sinusoidal in nature and thus the Fourier domain transforms appear to be most appropriate. Once digitized for computer compatibility, the amount of data needed to analyze the seismic waveforms can be reduced by the orthogonal transforms. A fast Fourier transform reduces the data needed to analyze the waveform by a factor of 10 (it would be a factor of 5 if both amplitude and phase spectra are used) with a very small percentage of the reconstructed root-mean-squared error. The fast Fourier transform accomplishes the data compression by changing the usual time domain representation of the seismic signal to one of frequency representation. A representation of the seismic wave requires less data points in the frequency domain than in the original time domain. A Walsh-Hadamard transform may also be used in a similar manner to yield a data compression factor of four. (The factor is reduced if the plus and minus signs are included.)

Haar transform and slant transform are more suitable for image processing than for seismic study. The discrete Chebyshev transform has the important advantage in that it is closest to KLT in mean square error while computable by fast algorithms. It does require much more computation time than Fourier or Walsh transforms. The Walsh transform is computationally the best. The data compression factor for DCT is nearly the same as for FFT. The DCT should be considered as a member of Fourier domain transforms with good promise for wide range of applications.

For seismic data study, the minimum mean squared error criterion, however, is of questionable value. Such criterion depends only up to the second order statistics (the mean and covariance functions) which may be not enough to characterize the seismic waves. Furthermore, reconstruction of the seismic wave is not an important objective. To estimate some parameters such as to determine the P-wave amplitude, and to discriminate explosion from earthquake, are among the important objectives of the seismic study. Both DCT and WHT spread the signal energy to higher spectral components than the FFT and thus may not be as effective in dimensionality reduction for pattern recognition as compared with FFT. Note that DCT is better than WHT in this sense. Unfortunately, the reduced feature space provided by all orthogonal transforms is still too large in dimension and the subsequent classifier is too complex in structure or computation. For two-dimensional display, the transformed data has to be considerably compressed further to make the display possible.

Therefore we conclude that the presently available orthogonal transforms have to be considerably improved for seismic study in processing, display, and discrimination. At the present time, the Fourier domian transforms are still most useful for seismic study. New transforms must be computable in fast algorithms while drastically compress the data so that the dimension of the reduced feature space falls below 10, which is a factor of 100 in reduction of 1024 data points typically used in digital seismic data study.

III. Computer Results

The seismic data considered is the ACDA Seismic Signature Data Base provided by Lt. Colonel Russell B. Ives. A complete spectral plot of all 269 records was submitted to him with report, "Fourier Spectral Plot of ACDA Seismic Signature Data Base", dated September 12, 1974. Some conclusions of the spectral analysis are:

1) With a few exceptions, all explosions have a pronounced spectral peak at 0.5 - 0.7 Hz.

2) The earthquakes have many discrete frequency components, i.e. they are rich in subharmonics.

3) The explosion spectra spread to higher frequencies than the earthquake spectra.

4) Most records have strong DC components which could be removed to provide better discrimination results.

An important reason for providing spectral plot of all records is to enable us to get an accurate interpretation of the results. In the attachments of this report we have included the following:

1. Computer program to plot the original seismic waveform with 1024 data points (samples) at 10 samples per second, and to plot the amplitude of FFT up to 5 Hz.

2. Application note on DCT.

3. Computer program to plot WHT and DCT.

4. A complete plot of DCT and WHT for each record. On each page there are two graphs, the upper one is for DCT up to 512 data points and the lower one is for WHT up to 1024 data points.

The following are conclusions which can be drawn from the plot of DCT and WHT:

1) DCT appears as a low-passed filtered WHT. Theoretical explanation of this phenomenon is not available. There might be some theoretical relationship between the two which is not yet discovered.

2) The DCT for explosion is a more smooth function of the number of data points than the earthquake.

3) The WHT is nearly periodic (except in amplitude) with a period of approximately 256 data points.

Attachment #1 Computer Program to Plot Seismic Wave and its Amplitude Spectrum for PDP 11-45 Computer


```
0001            DIMENSION C(257)
0002            COMPLEX E(2000)
0003            REAL X(2,2000), B(2000)
0004            BYTE IA(70), IX(9), IQ(10), TEST
0005            EQUIVALENCE (E,X)
0006            DATA TEST,IX,IQ/'X','E','X','P','L','O','S','I','O','N',
               +                'E','A','R','T','H',' ','Q','U','A','K','E'/
0007            CALL XYINIT(B,2000)
0008            CALL SIZE(C,1024)
0009            CALL CHSIZE(0.4,90.0)
0010      6     FORMAT(I3)
0011      7     IC=0
0012      1     READ(6,6)IF
0013            DO 9 I=1,2000
0014            X(2,I)=0.0
0015      9     X(1,I)=0.0
0016      11    IC=IC+1
0017            READ(1,END=10)IA
0018            READ(1)NPT,(X(1,I), I=1,NPT)
0019            IF(IF.GE.IC) GO TO 8
0020            REWIND 1
0021            GO TO 7
0022      8     IF(IF.NE.IC) GO TO 11
0023            CALL IXYPT(230,0,0)
0024            CALL XYCHAR(IA,20)
0025            CALL IXYPT(486,0,0)
0026            IF(IA(70).EQ.TEST) GO TO 2
0027            CALL XYCHAR(IQ,10)
0028            GO TO 3
0029      2     CALL XYCHAR(IX,9)
0030      3     CALL IXYPT(500,0,0)
0031            CALL IXYPT(2190,0,1)
0032            XMAX=X(1,1)
0033            XMIN=XMAX
0034            DO 4 I=1,NPT
0035            IF(XMIN.GT.X(1,I)) XMIN=X(1,I)
0036      4     IF(XMAX.LT.X(1,I)) XMAX=X(1,I)
0037            XS=1690.0/(XMAX-XMIN)
0038            N=2190.0+XMIN*XS
0039            CALL IXYPT(N,0,0)
0040            CALL IXYPT(N,4000,1)
0041            IXX=0
0042            IY=2190.0+(XMIN-X(1,1))*XS
0043            CALL IXYPT(IY,IXX,0)
0044            DO 5 I=2,NPT
0045            IXX=I+I-2
0046            IY=2190.0+(XMIN-X(1,I))*XS
0047      5     CALL IXYPT(IY,IXX,1)
0048            CALL IXYPT(2390,0,0)
0049            CALL IXYPT(4090,0,1)
0050            CALL IXYPT(4090,4095,1)
0051            NP=NPT-1024
0052            IF(NP.GT.0) CALL SHIFTL(X,2000,NP)
0053            CALL FFOUR(X,1024,C,-1.0)
0054            XMAX=CABS(E(1))
```

Attachment #1 continued

```
FORTRAN V004A                          00:00:00     21-SEP-74    PAGE     2

0055            DO 12 I=1,512
0056            X(1,I)=CABS(E(I))
0057    12        IF(XMAX.LT.X(1,I)) XMAX=X(1,I)
0058              XS=1690.0/XMAX
0059            N=4090.0-X(1,1)*XS
0060            CALL IXYPT(N,0,0)
0061            DO 13 I=1,512
0062              IXX=8*I-4
0063            IY=4090.0-X(1,I)*XS
0064    13      CALL IXYPT(IY,IXX,1)
0065            CALL IXYPT(0,4095,0)
0066            CALL IXYPT(0,0,0)
0067            CALL IXYPT(4095,0,0)
0068            CALL IXYPT(4095,4095,0)
0069            GO TO 1
0070    10      CALL XYEND
0071            CALL EXIT
0072            END

        ROUTINES CALLED:
        XYINIT, SIZE  , CHSIZE, IXYPT , XYCHAR, SHIFTL, FFOUR
        CABS  , XYEND , EXIT

        SWITCHES = /ON

        BLOCK        LENGTH
        MAIN.    13422  (064334)*

        **COMPILER ----- CORE**
           PHASE       USED  FREE
        DECLARATIVES 00366 05535
        EXECUTABLES  00937 04964
        ASSEMBLY     01478 07340
```

Attachment #2 Application Note on DCT

DCT - Discrete Chebyshev Transform

A. Implementation:

The Discrete Chebyshev Transform of a data set y(m) is defined by [1]

$$Y(k) = \frac{A}{N} \mathrm{Re}\left\{ e^{-k\pi i/2N} \sum_{m=0}^{N-1} y(m) e^{-2mk\pi i/2N} \right\}$$

$$k = 0,1,\ldots,N-1$$

$$\text{and } A = \begin{cases} \sqrt{2} & k = 0 \\ 2 & k = 1,2,\ldots,N-1 \end{cases}$$

The DCT program evaluates this expression utilizing an in-place, 4N-point Fast Fourier Transform; the various parameters employed are as follows:

N = number of data pts y(m)
= 2^p where p is integral
N2 = 2N
N4 = 4N
NM = number of sub-matrices employed in the FFT
= p + 2
Sign = -1.0 for forward transform
= +1.0 for inverse transform

Because the computations are done in-place, Y is both input and output arrays; X is a complex buffer array.

The program generates 2N output coefficients, of which the first N contain the correctly-ordered, desired output. Although this program utilizes an FFT, unlike the FFT only the 2N real output points from the forward transform are required to generate the inverse.

B. Program Notes

The FFT employed is Robinson's decimation-in-frequency algorithm[2]. The 'phase-shift' operates on the complex X array only when its components represent functions of k; i.e., for the forward transform the FFT is done first, then the array is phase-shifted; for the inverse transform the reverse procedure is followed.

Each time the FFT is performed, the bit-reversed outputs are unscrambled within the subroutine to produce a sequentially-ordered array; the output consists of the real component of the complex array.

C. References

1. N. Ahmed, T. Natarajan, and K. R. Rao, IEEE Trans. Computers, C-23, 90(1974).

2. E. A. Robinson, Multichannel Time Series Analysis, Holden-Day, San Francisco, 1967.

Attachment #3 Computer Program to Plot DCT and WHT


```
      DIMENSION Z(1024)
      DIMENSION Y(1024), MM(12)
      REAL X(2,2048), B(100)
      BYTE IA(70), IX(9), IQ(10), TEST
      EQUIVALENCE (E,X)
      DATA TEST,IX,IQ/'X','E','X','P','L','O','S','I','O','N',
     +                'E','A','R','T','H','Q','U','A','K','E'/
      CALL XYINIT(8,100)
      CALL CHSIZE(0.4,90.0)
    6 FORMAT(I3)
    7 IC=0
    1 READ(6,6)IF
        DO 20 I=1,1024
   20   Y(I)=0.0
   11 IC=IC+1
      READ(1,END=10)IA
      READ(1)NPT,(Y(I), I=1,NPT)
      IF(IF.GE.IC) GO TO 8
      REWIND 1
      GO TO 7
    8 IF(IF.NE.IC) GO TO 11
      CALL IXYPT(230,0,0)
      CALL XYCHAR(IA,20)
      CALL IXYPT(486,0,0)
      IF(IA(70).EQ.TEST) GO TO 2
      CALL XYCHAR(IQ,10)
      GO TO 3
    2 CALL XYCHAR(IX,9)
    3 CALL IXYPT(500,0,0)
      CALL IXYPT(2190,0,1)
        DO 15 I=1,1024
   15   Z(I)=Y(I)
      CALL DCT(512,1024,2048,11,MM,X,Y,-1.0)
      XMAX=Y(1)
      XMIN=XMAX
      DO 4 I=2,512
      IF(XMIN.GT.Y(I)) XMIN=Y(I)
    4 IF(XMAX.LT.Y(I)) XMAX=Y(I)
      XS=1690.0/(XMAX-XMIN)
      N=2190.0+XMIN*XS
      CALL IXYPT(N,0,0)
      CALL IXYPT(N,4000,1)
        IXX=0
        IY=2190.0+(XMIN-Y(1))*XS
      CALL IXYPT(IY,IXX,0)
      DO 5 I=2,NPT
      IXX=4*I-4
      IY=2190.0+(XMIN-Y(I))*XS
    5 CALL IXYPT(IY,IXX,1)
      CALL IXYPT(2390,0,0)
      CALL IXYPT(4090,0,1)
        DO 9 I=1,1024
        X(1,I)=Z(I)
    9   X(2,I)=0.0
        DO 14 I=1025,2048
```

Attachment #3 continued

```
FORTRAN V004A                    00:00:00    21-SEP-74    PAGE     2

                X(1,I)=0.0
        14      X(2,I)=0.0
              CALL FWT(X,1024)
              XMAX=X(1,I)
              XMIN=XMAX
              DO 12 I=1,1024
              IF(XMIN.GT.X(1,I)) XMIN=X(1,I)
        12    IF(XMAX.LT.X(1,I)) XMAX=X(1,I)
              XS=1690.0/(XMAX-XMIN)
              N=4090.0+XMIN*XS
              CALL IXYPT(N,0,0)
              CALL IXYPT(N,4095,1)
              N=4090.0+(XMIN-X(1,1))*XS
              CALL IXYPT(N,0,0)
              DO 13 I=2,1024
              IXX=4*I-4
              IY=4090.0+(XMIN-X(1,I))*XS
        13    CALL IXYPT(IY,IXX,1)
              CALL IXYPT(0,4095,0)
              CALL IXYPT(0,0,0)
              CALL IXYPT(4095,0,0)
              CALL IXYPT(4095,4095,0)
              GO TO 1
        10    CALL XYEND
              CALL EXIT
              END

ROUTINES CALLED:
XYINIT, CHSIZE, IXYPT , XYCHAR, DCT   , FWT   , XYEND
EXIT

SWITCHES = /ON,/SU

BLOCK          LENGTH
MAIN.     13316  (064010)*

**COMPILER ----- CORE**
   PHASE        USED  FREE
DECLARATIVES 00366 05529
EXECUTABLES  00937 04958
ASSEMBLY     01472 07340
```

Attachment #4

Plot of DCT and WHT for

ACDA Seismic Signature Data Base

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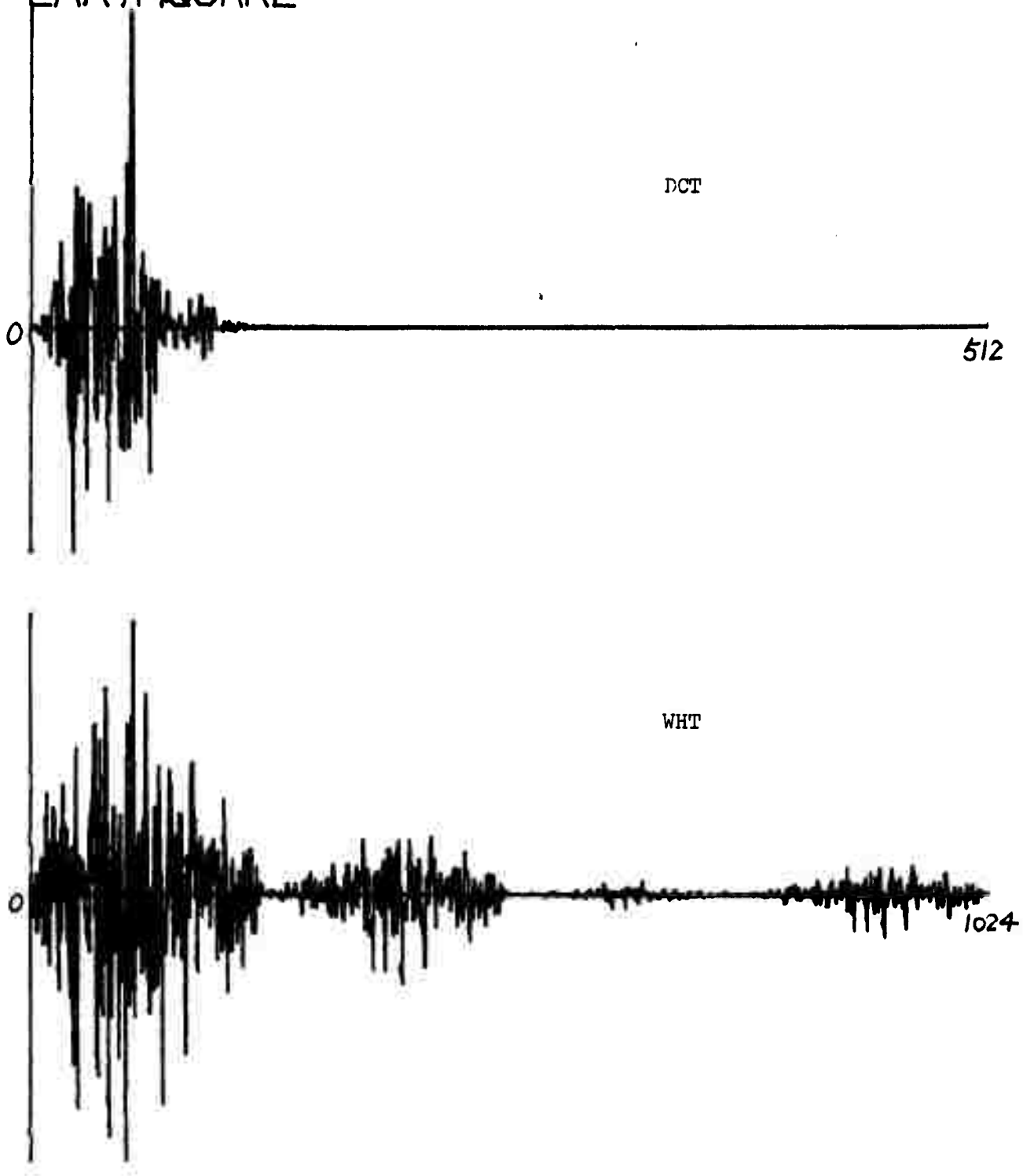

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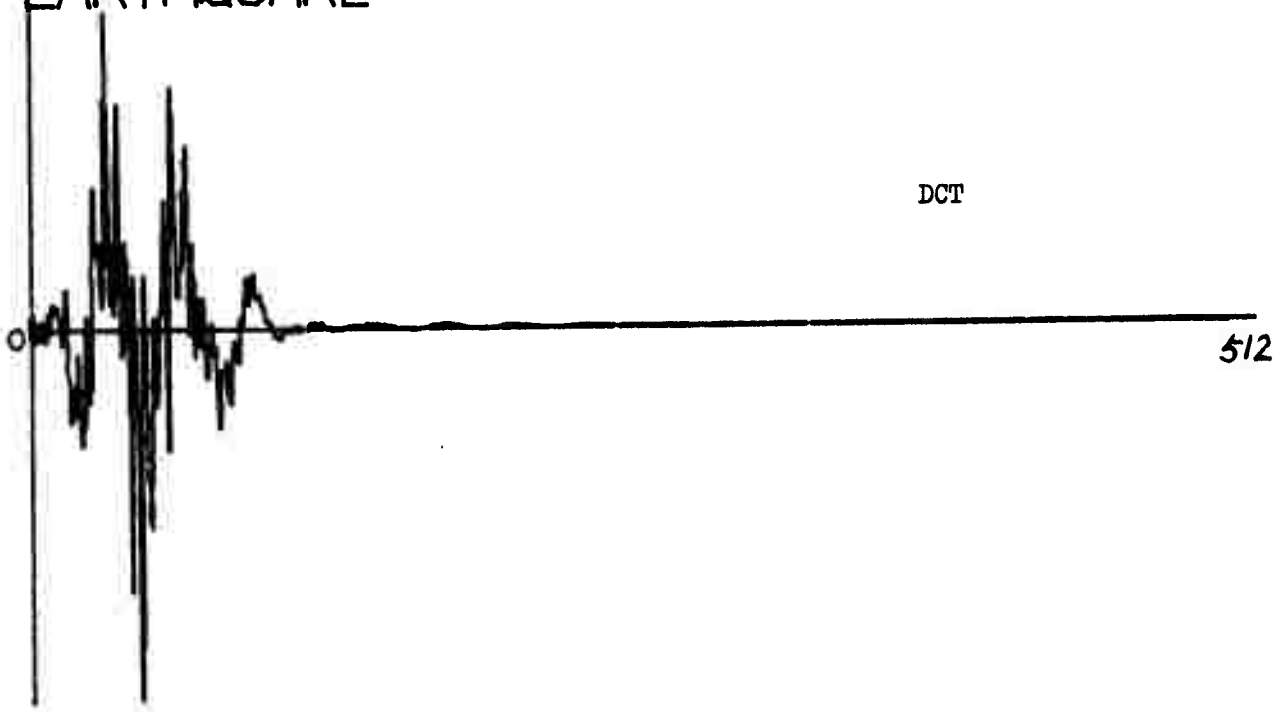

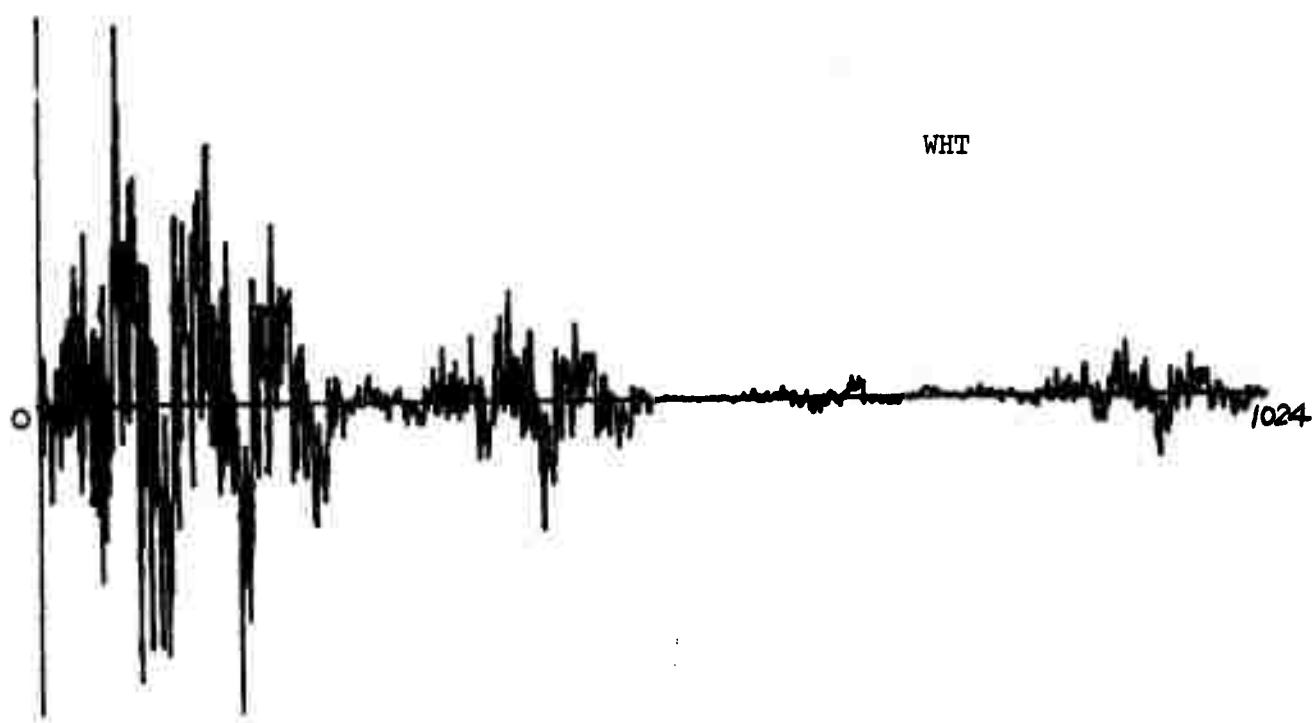

Q006

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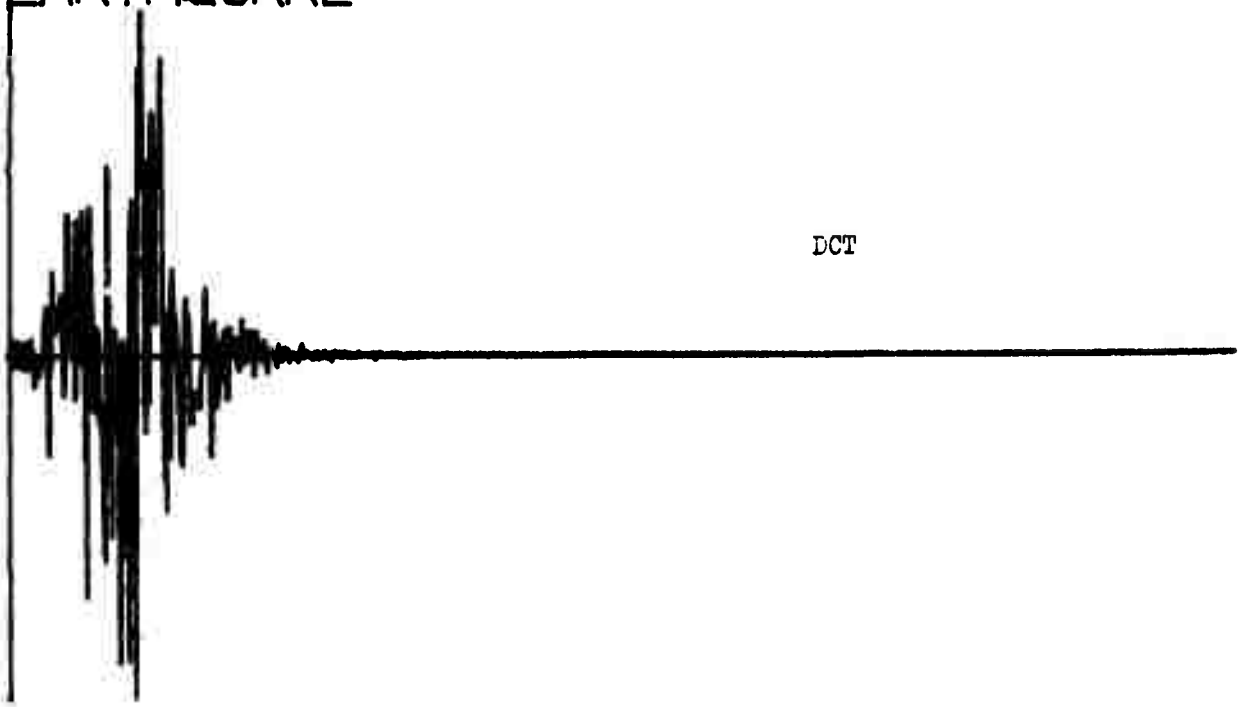

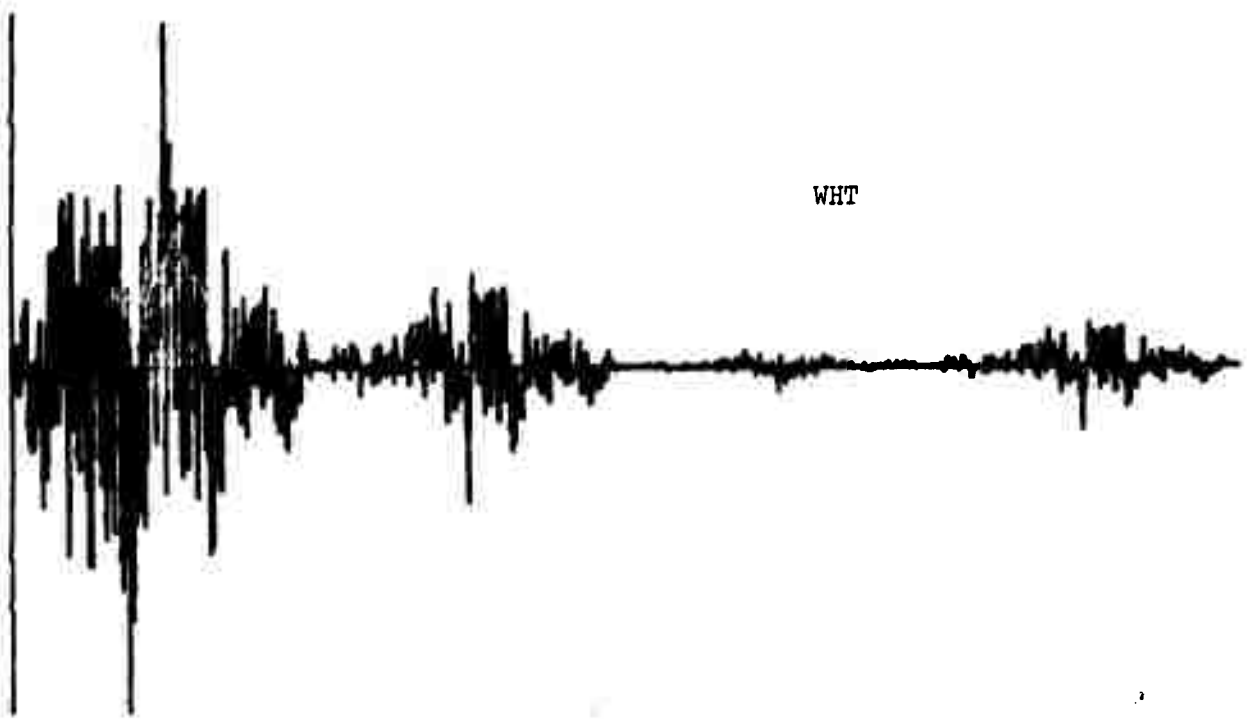

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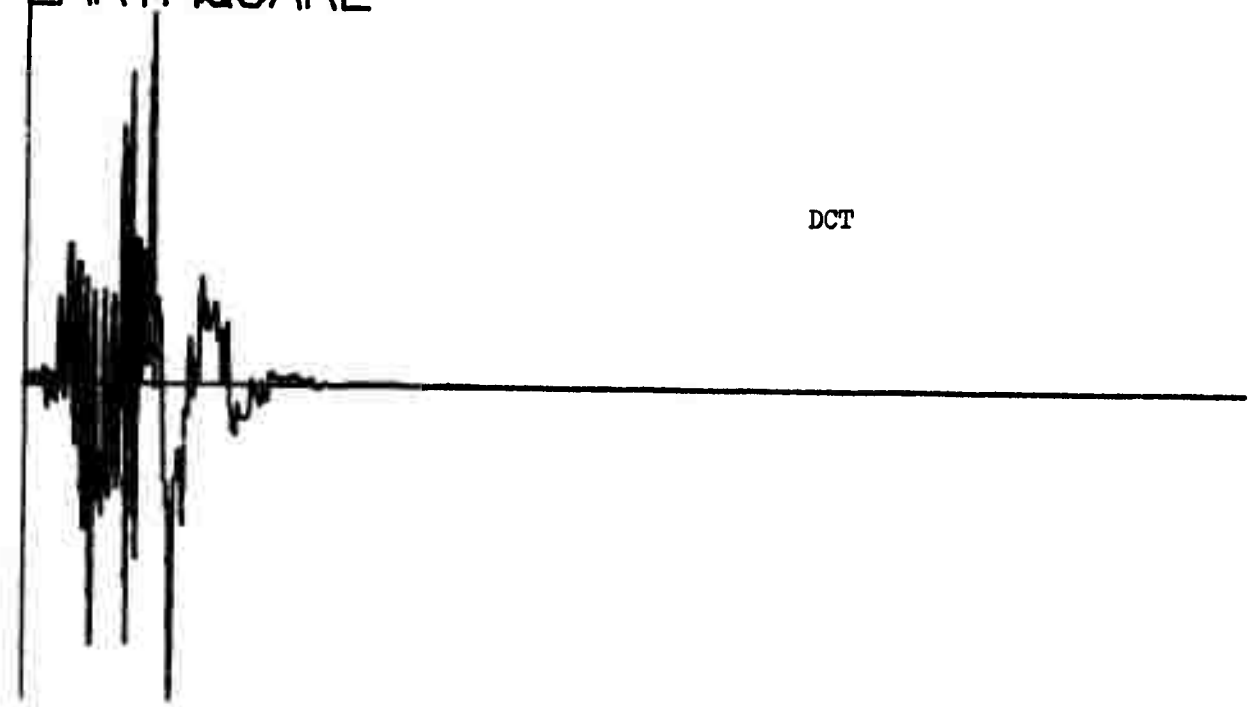

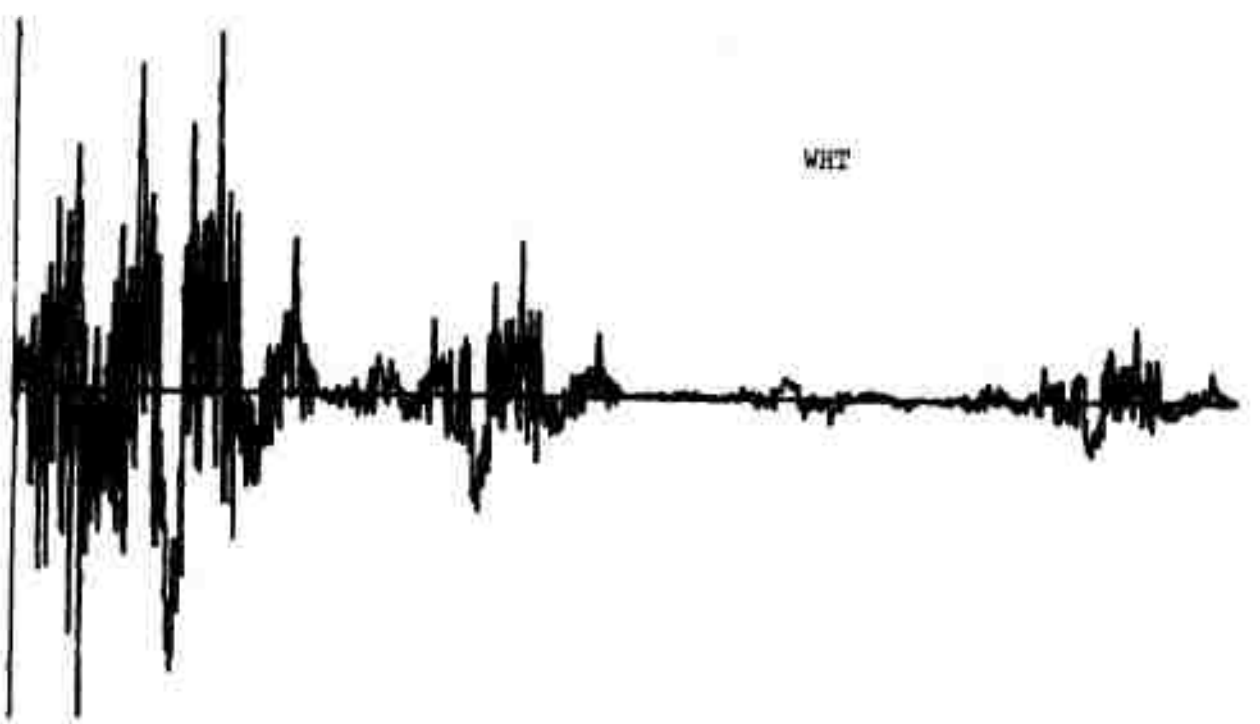

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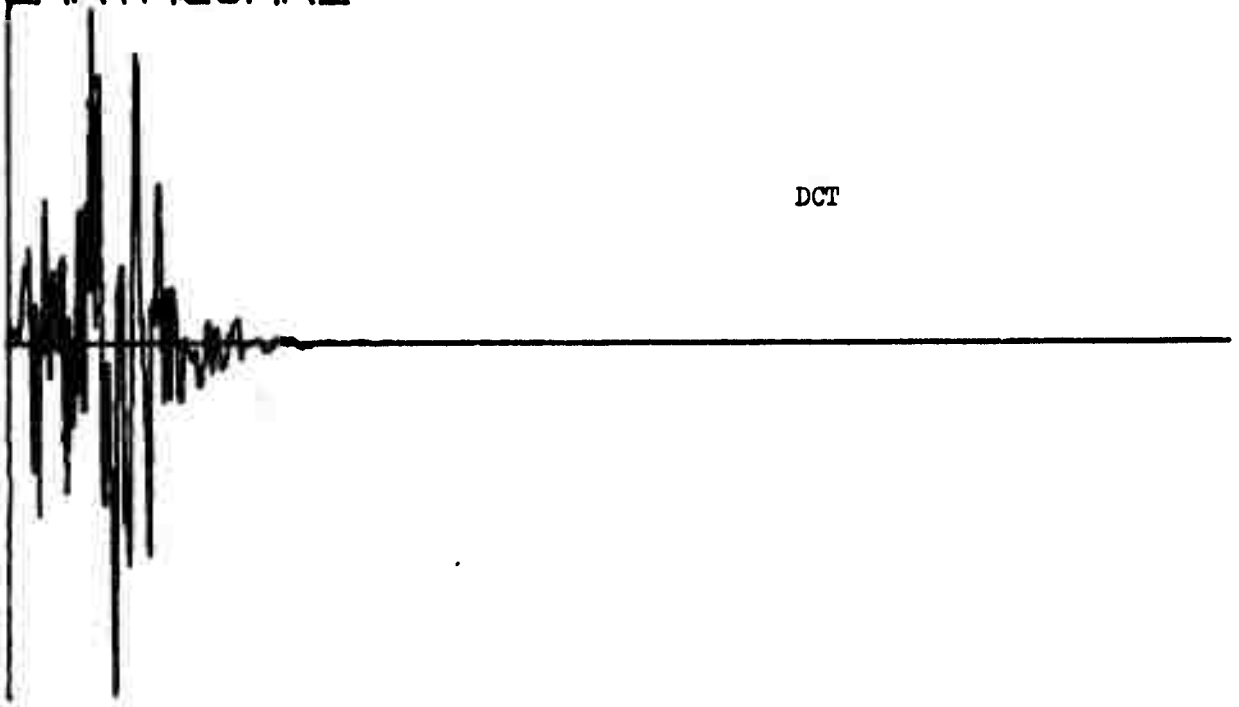

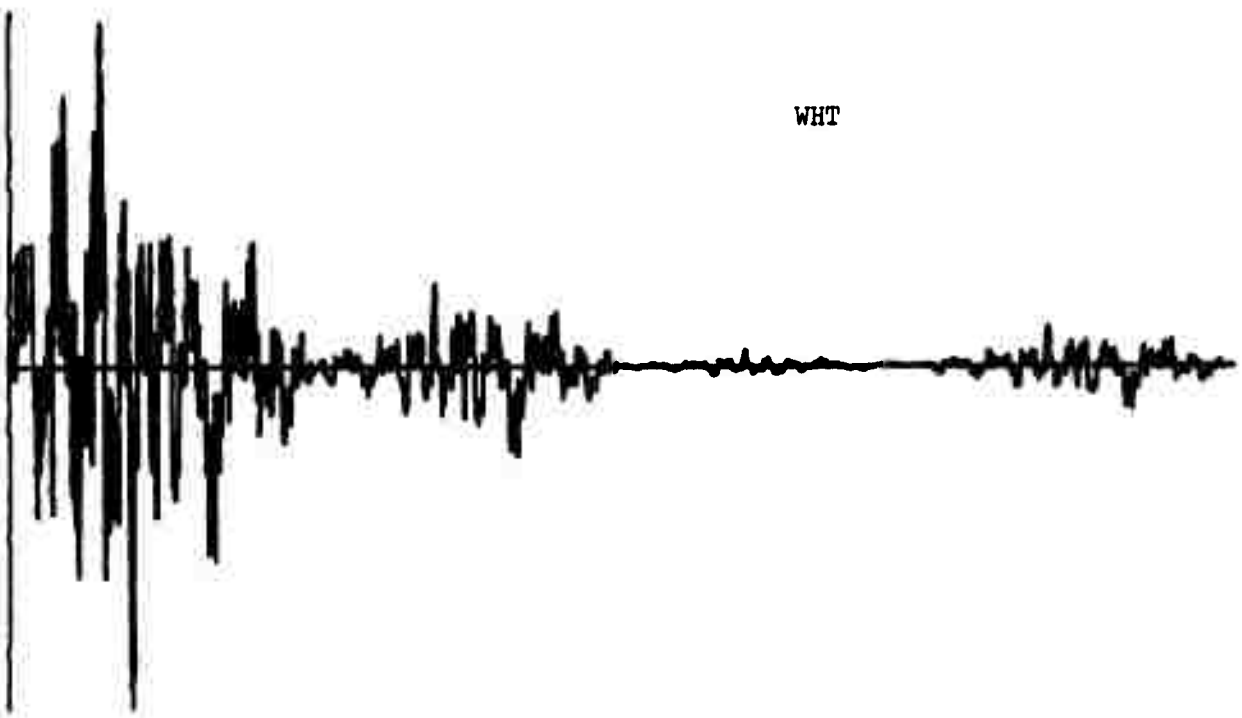

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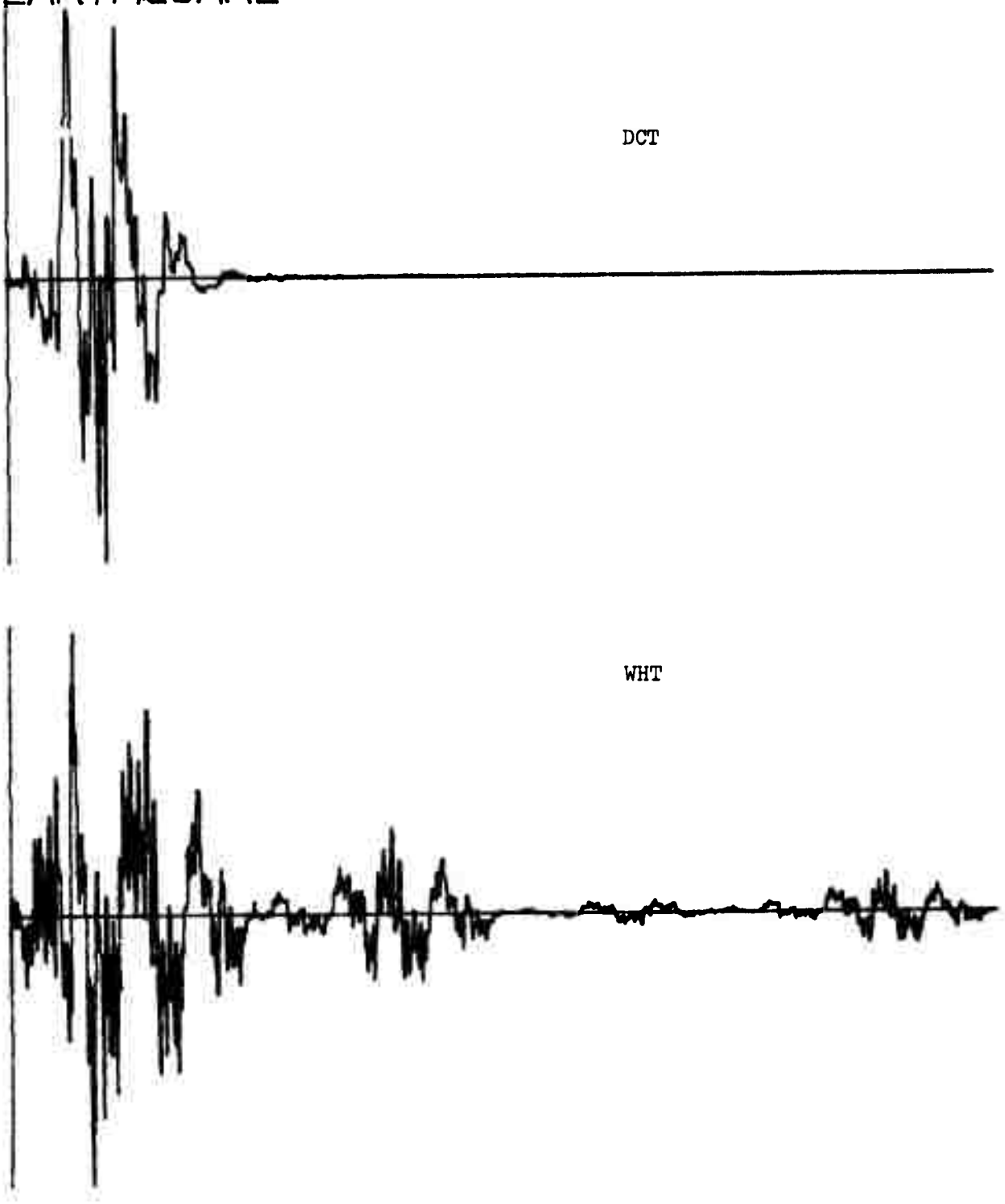

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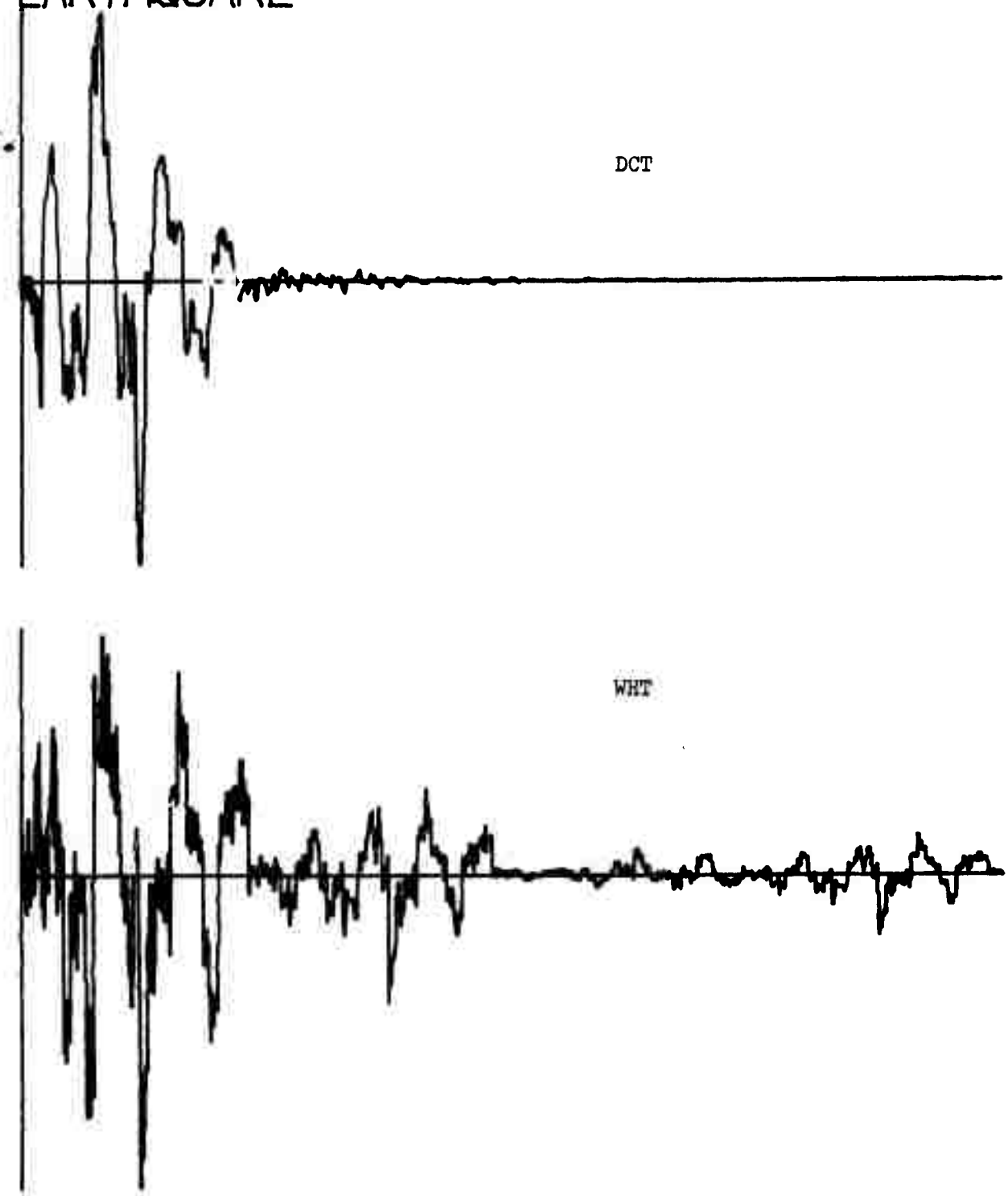

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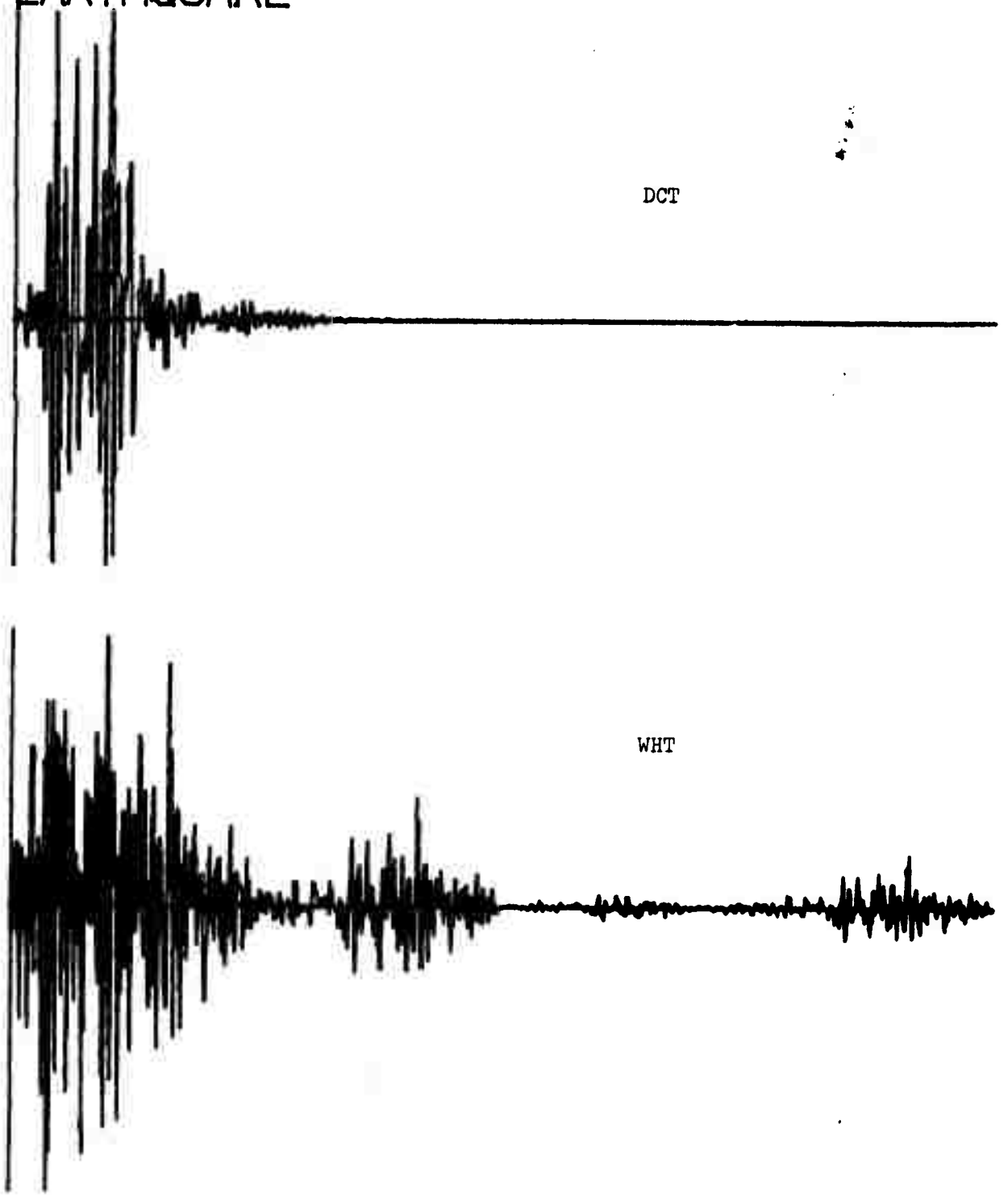

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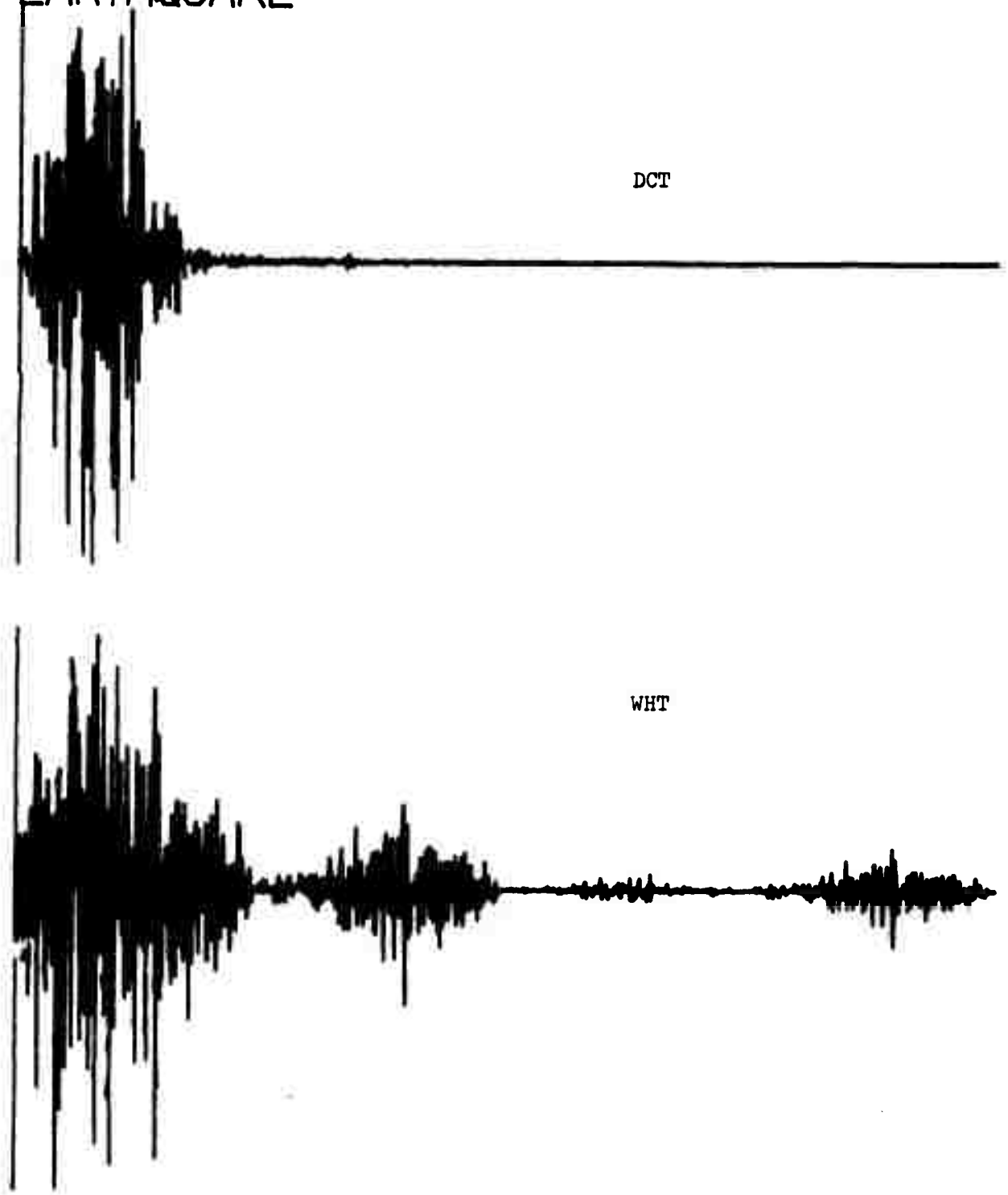

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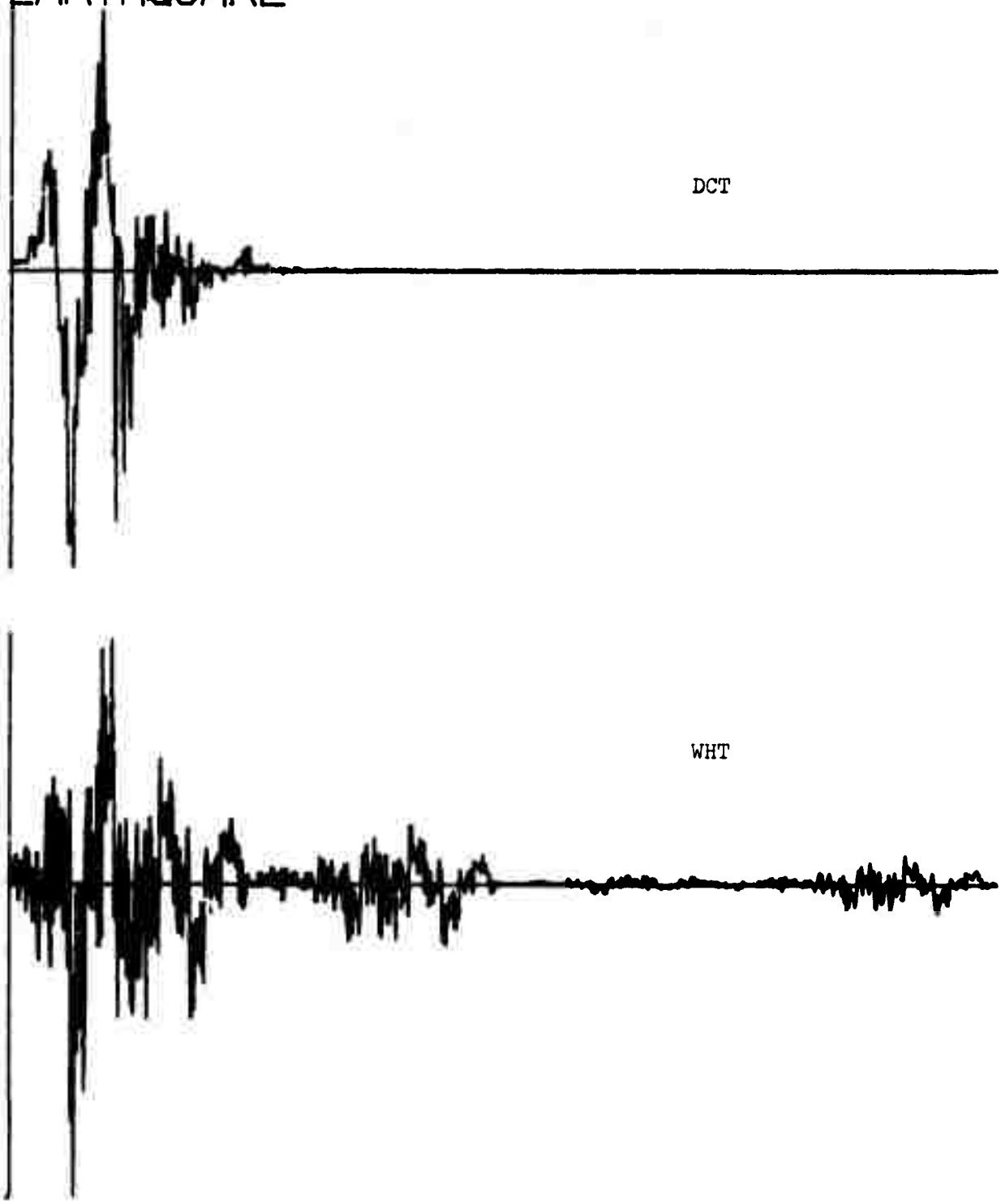

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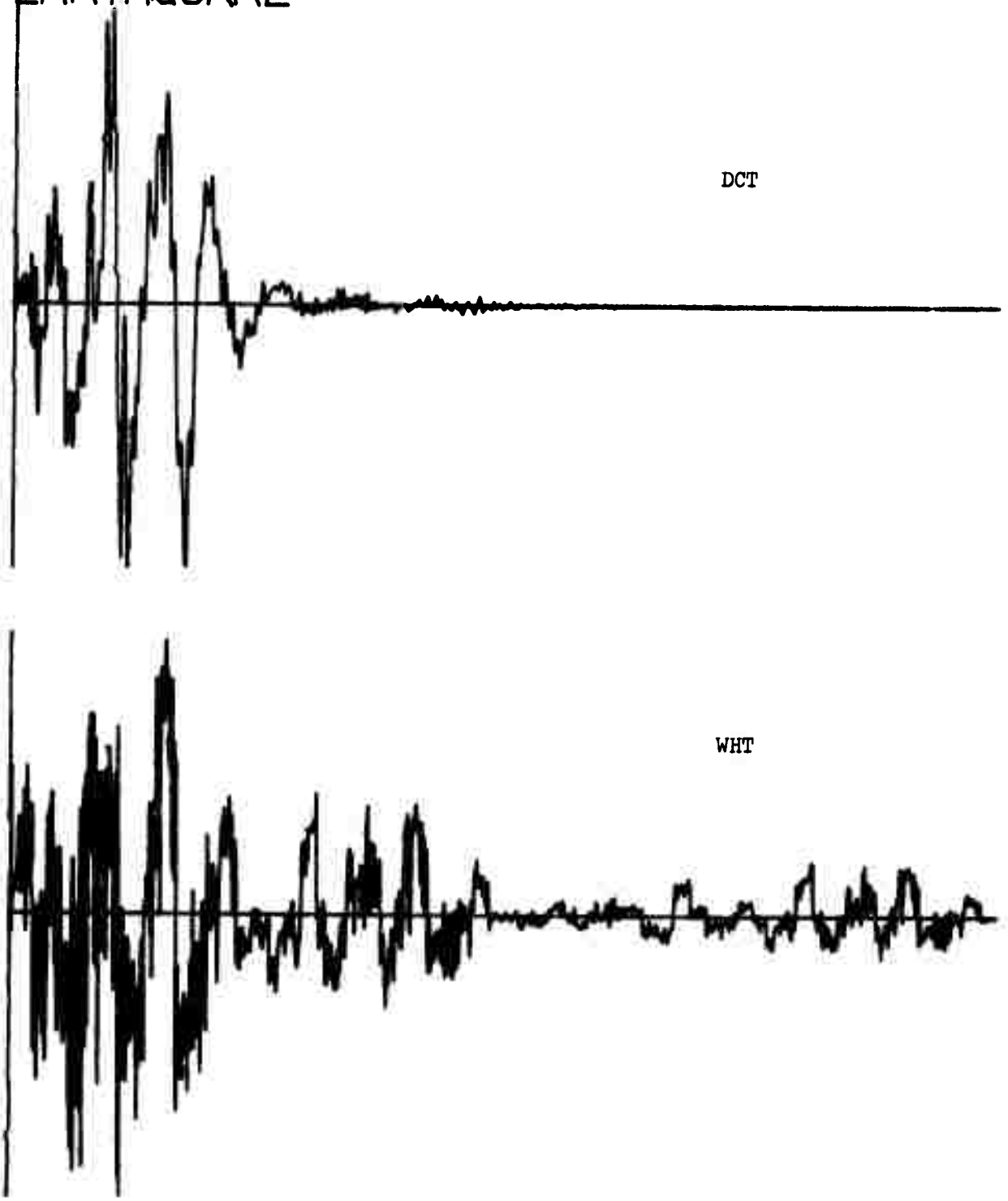

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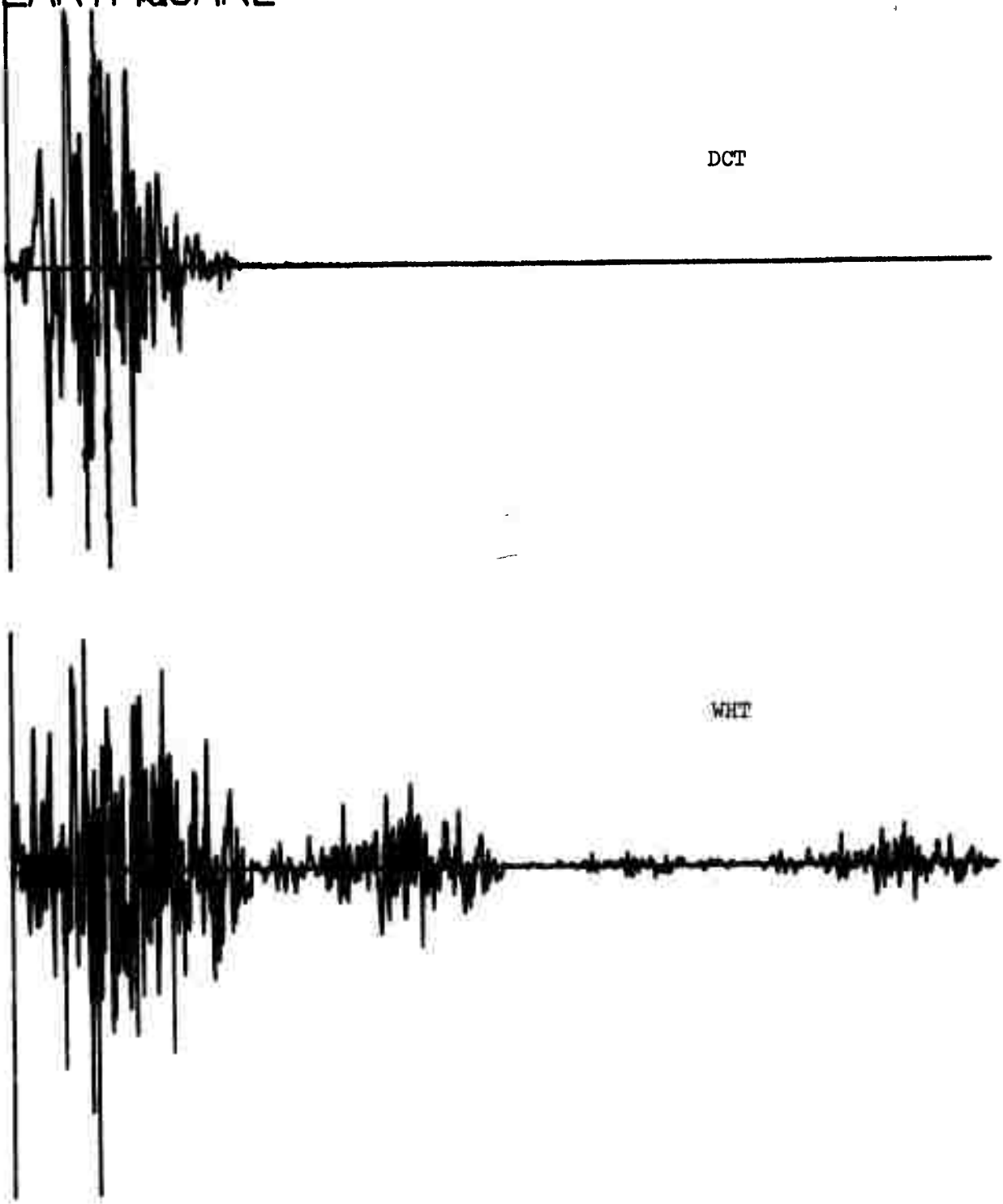

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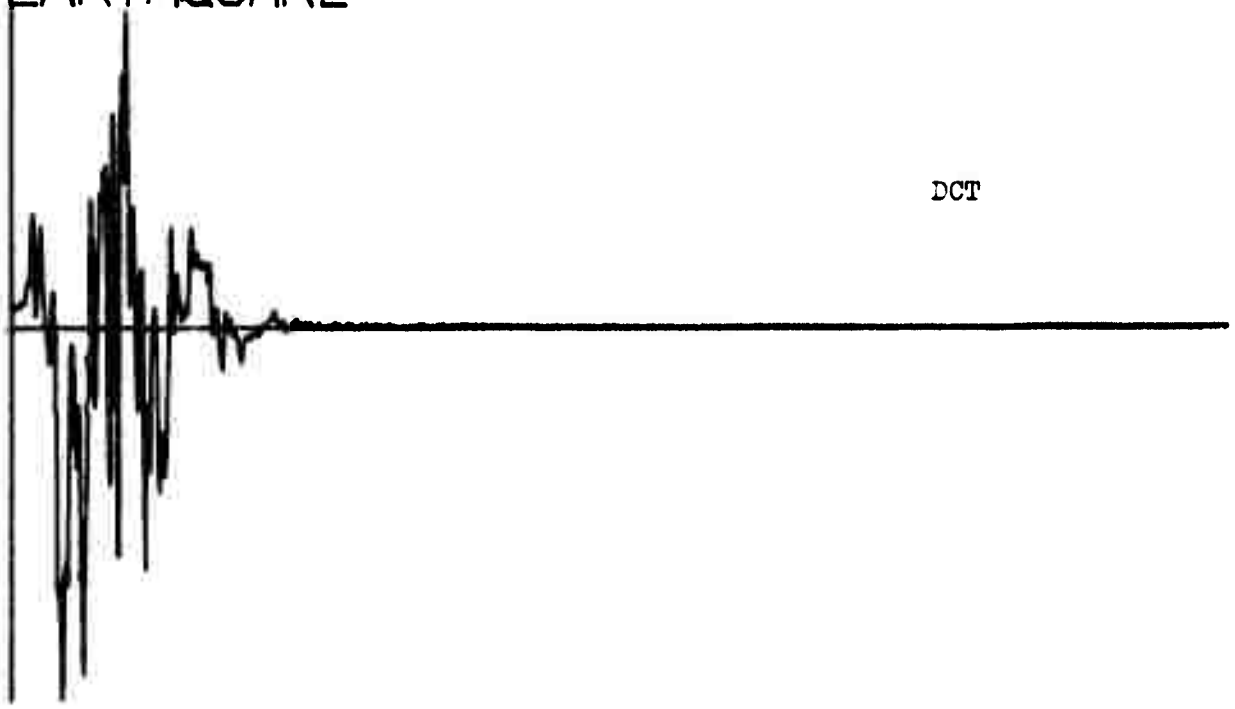
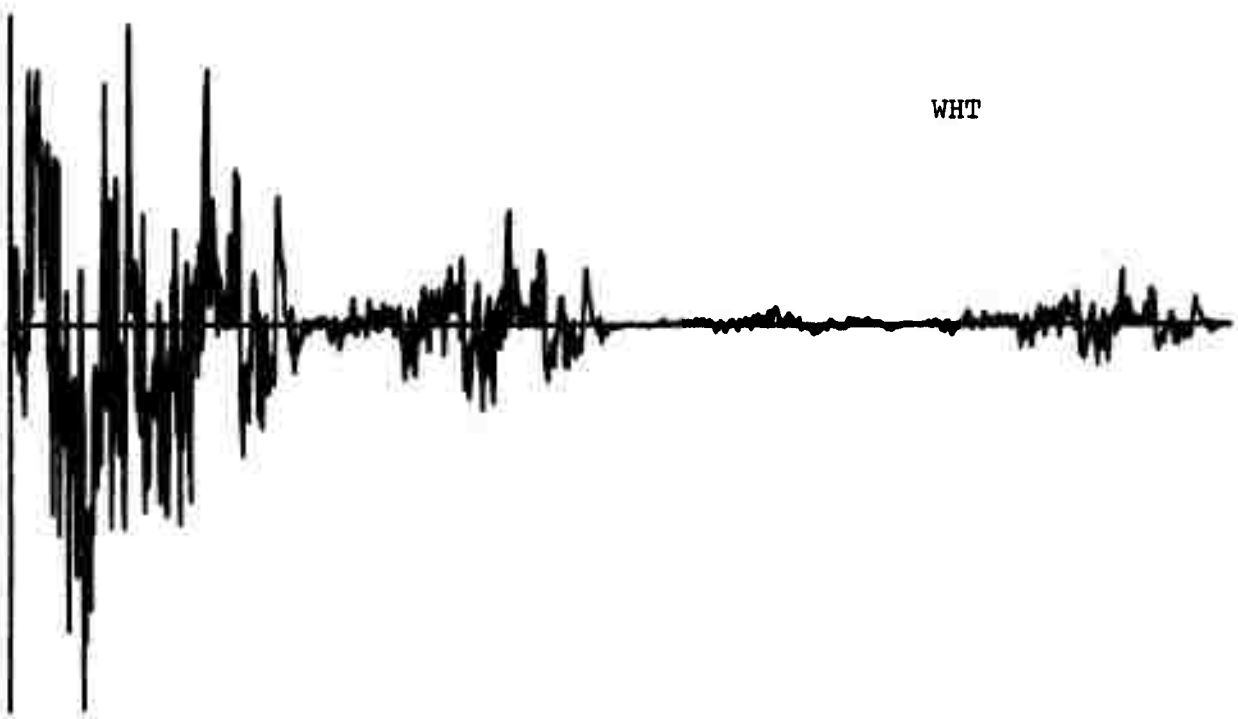
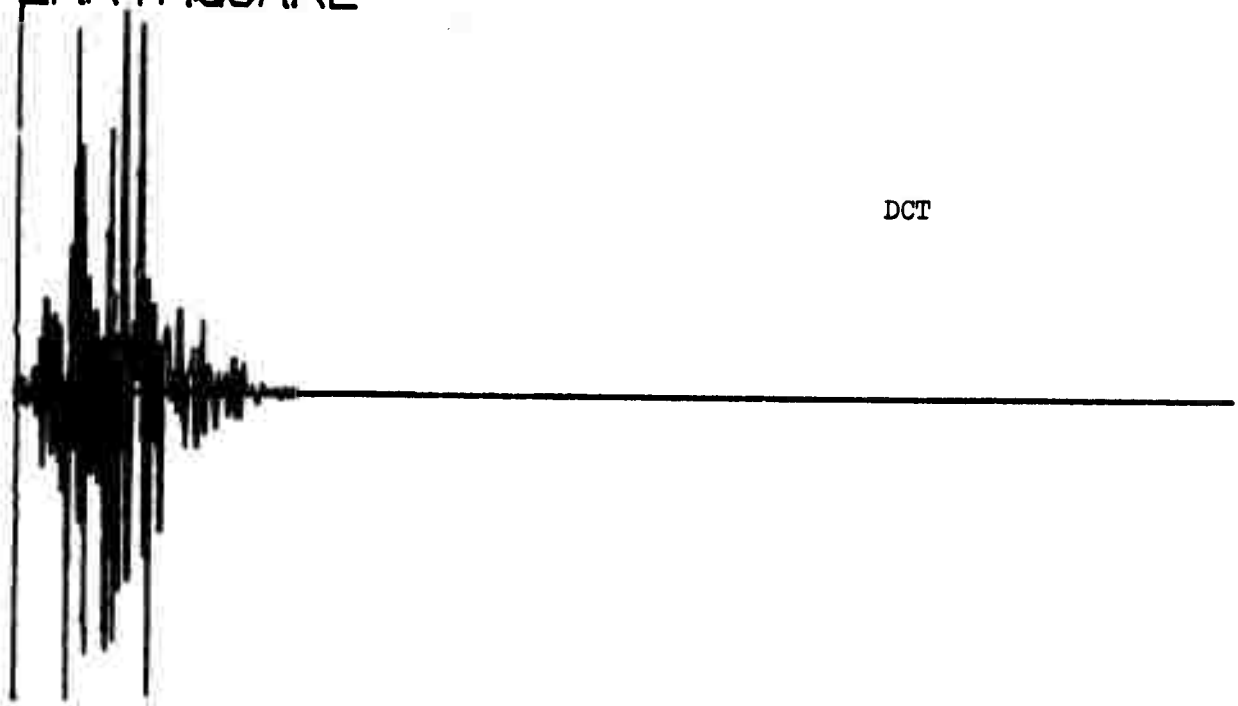
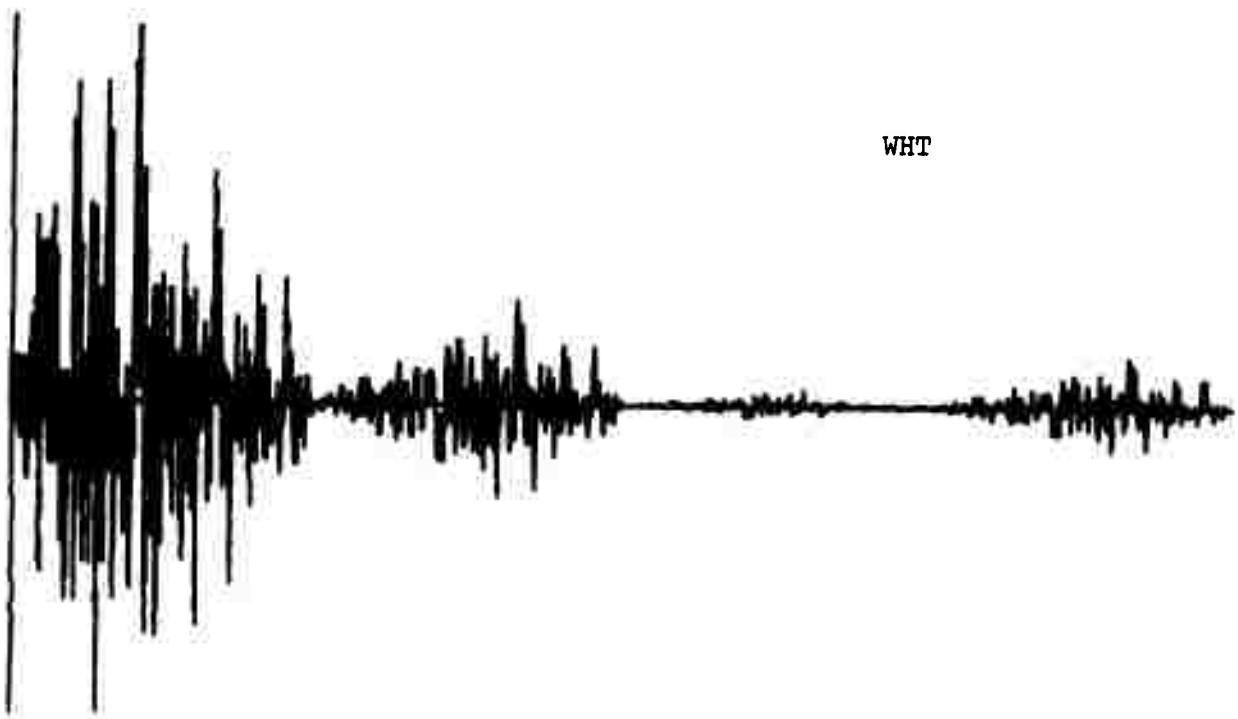




EVENT NUMBER 2018
EARTHQUAKE

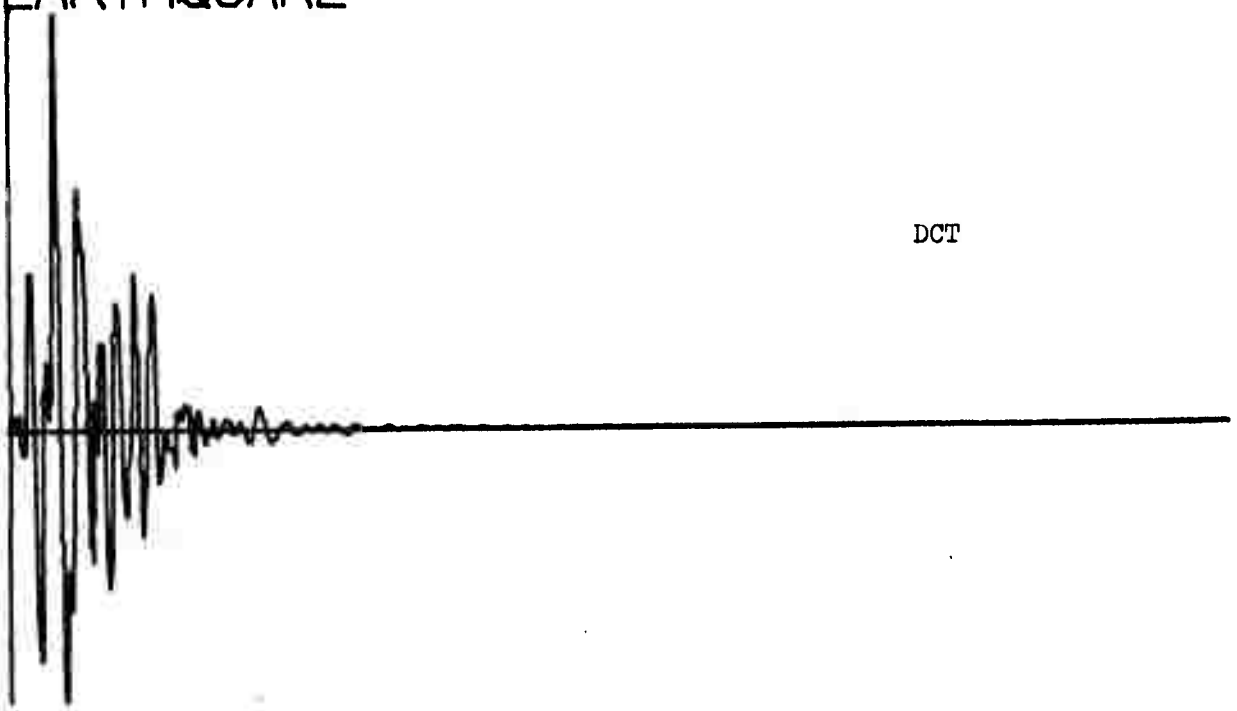


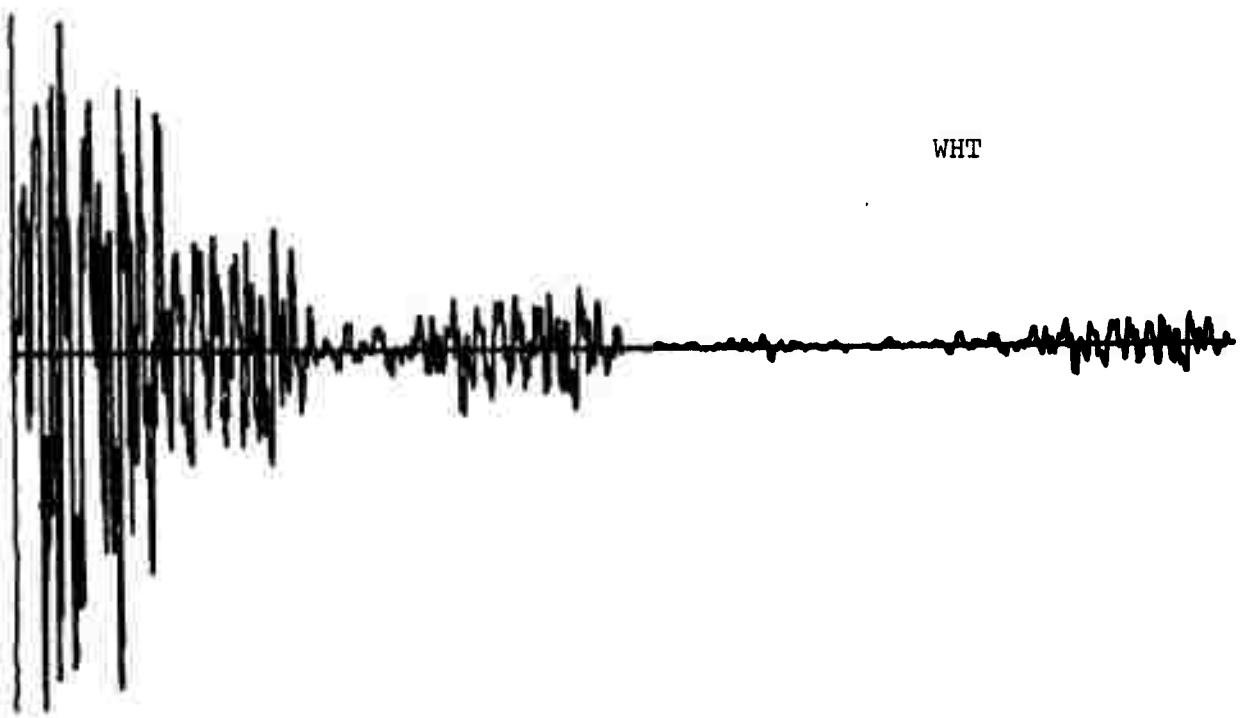
DCT



WHT

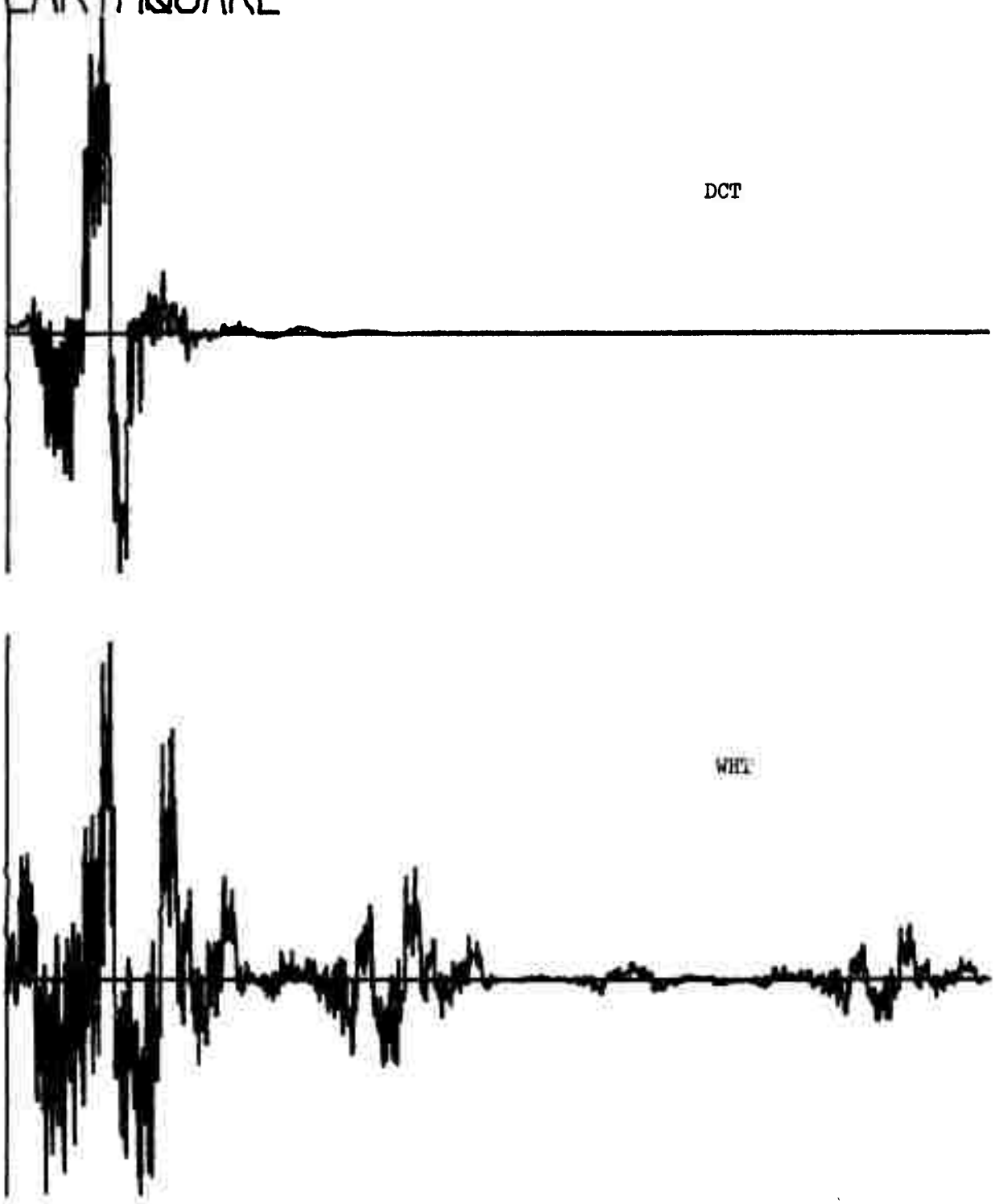
EVENT NUMBER 2016
EARTHQUAKE



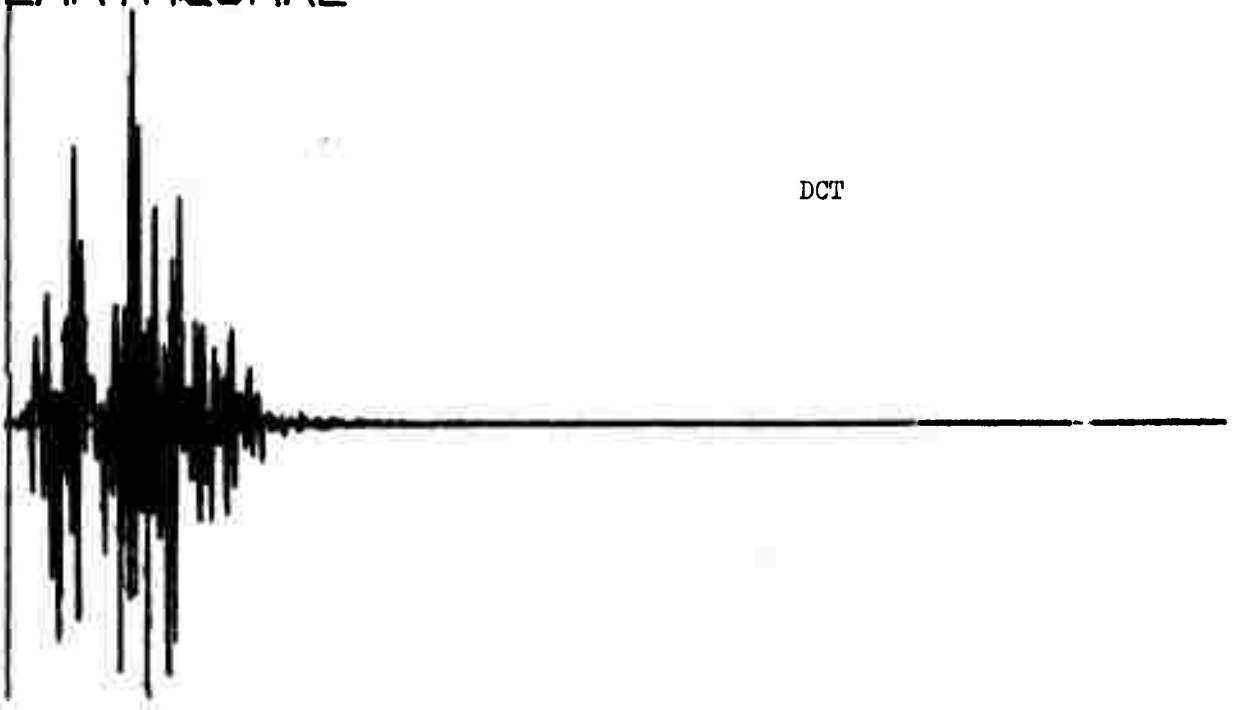


EVENT NUMBER 2008

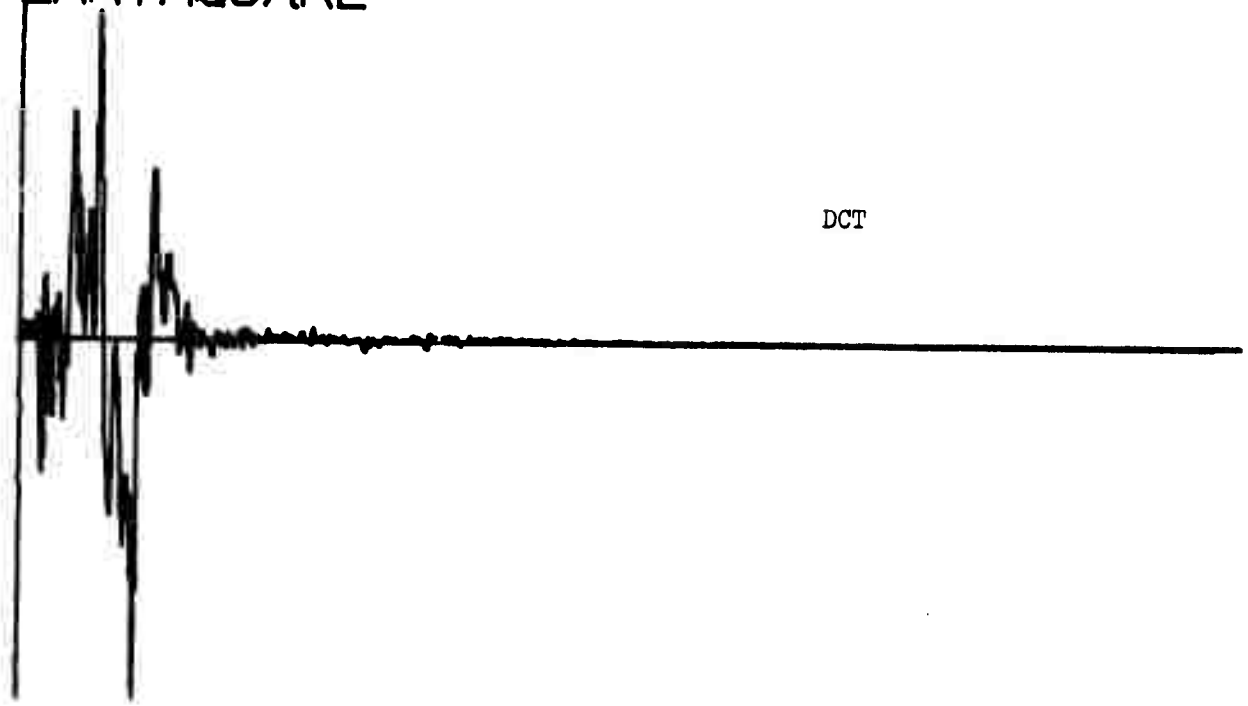
EARTHQUAKE

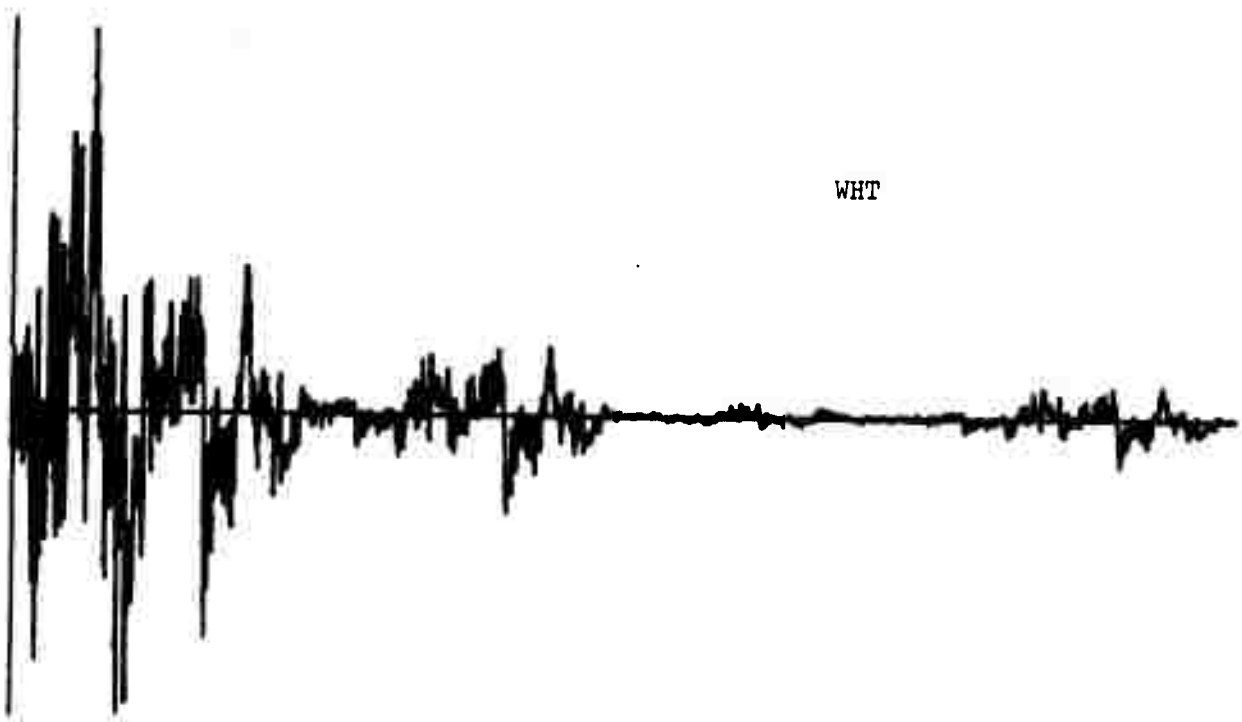


EVENT NUMBER 2020
EARTHQUAKE

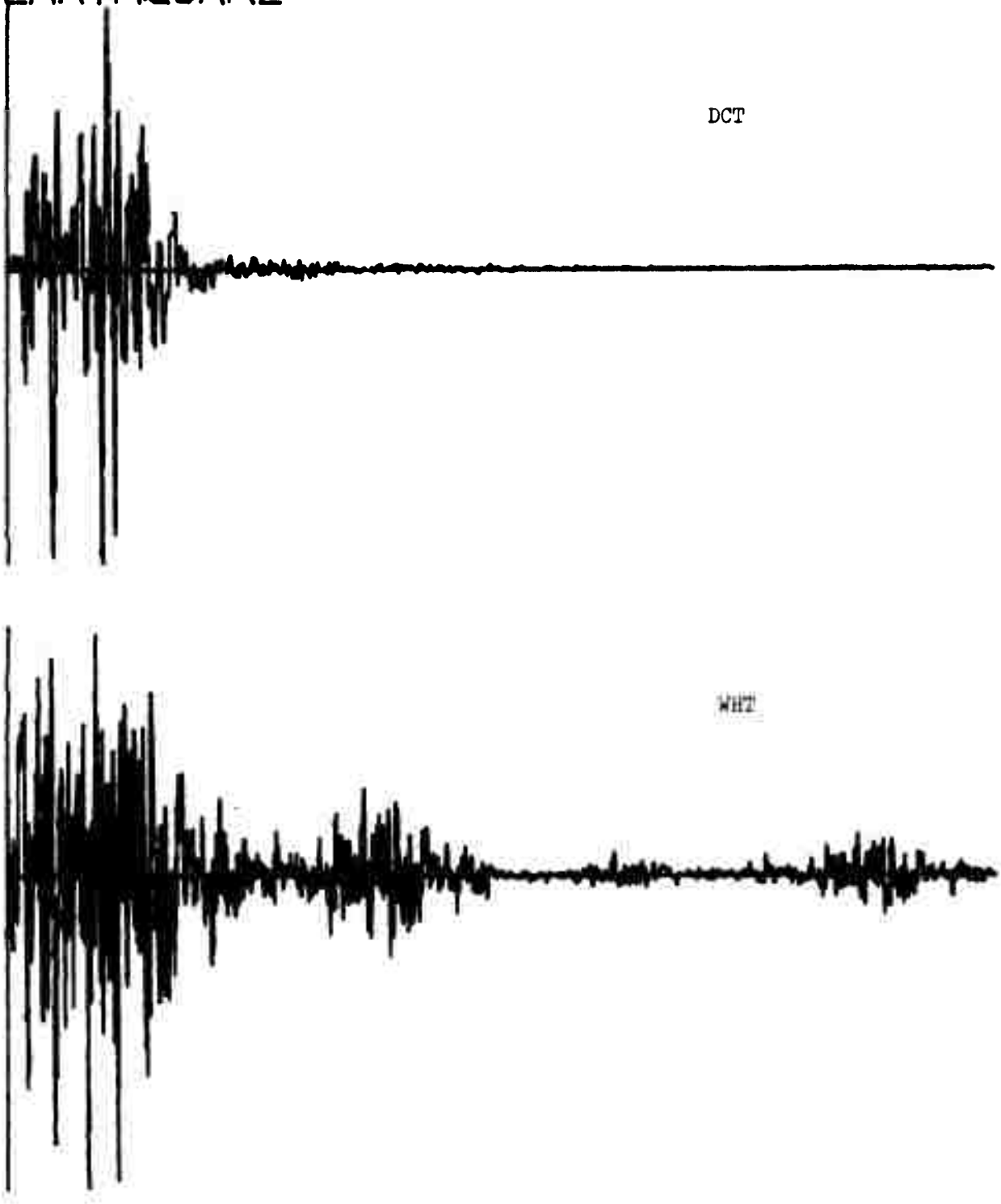


EVENT NUMBER 2023
EARTHQUAKE

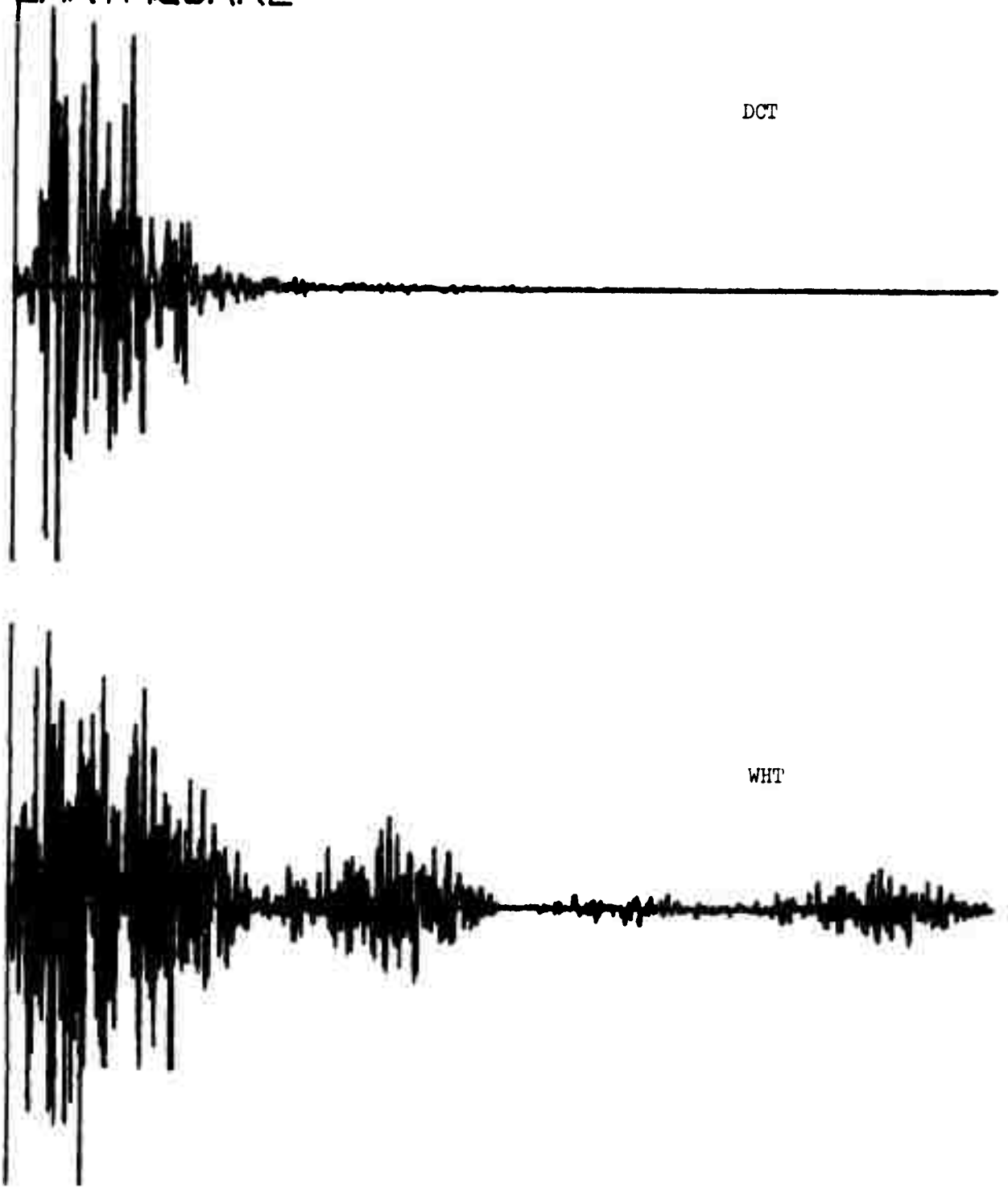




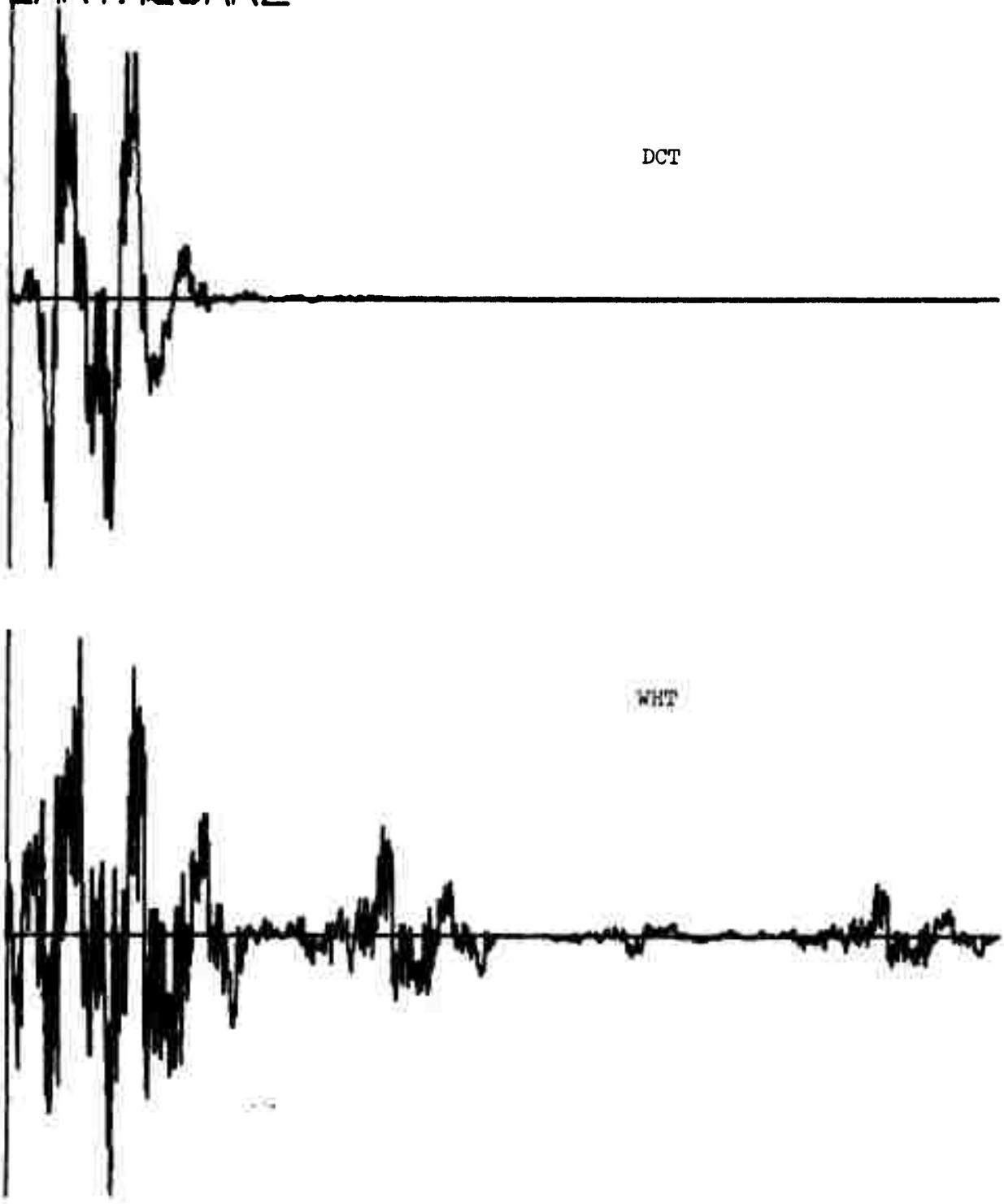
EVENT NUMBER 2025
EARTHQUAKE



EVENT NUMBER 2026
EARTHQUAKE



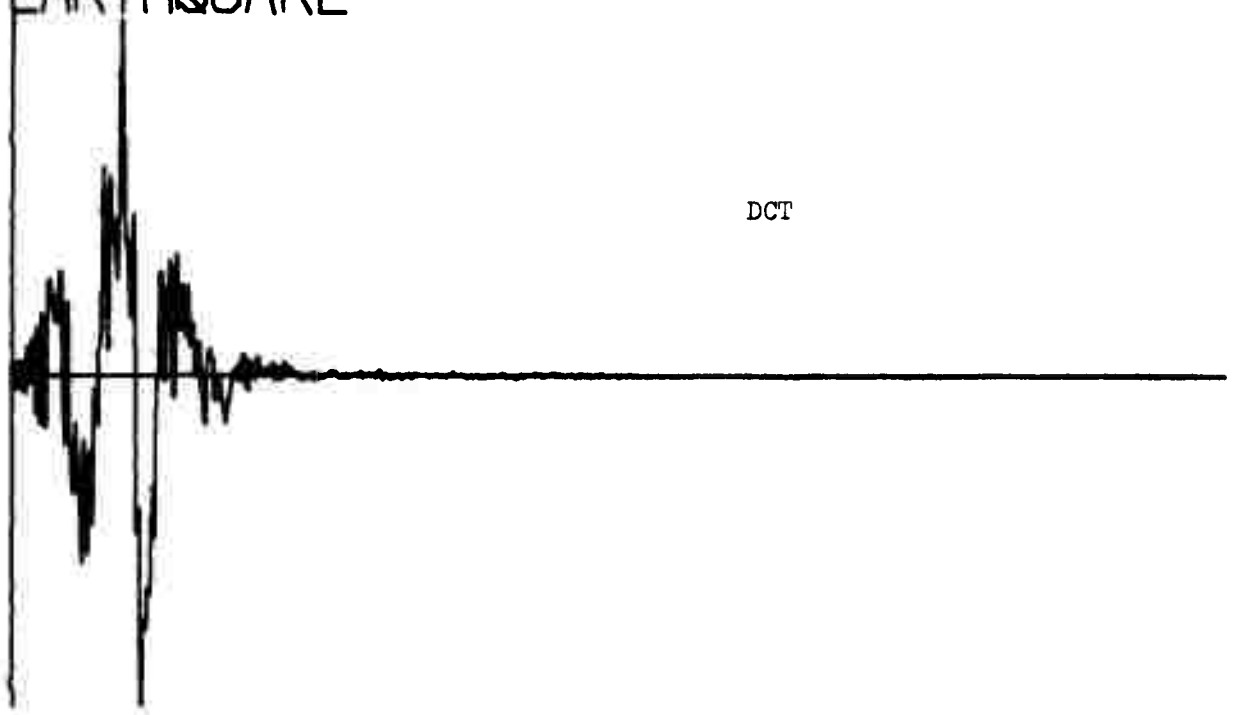
EVENT NUMBER 2027
EARTHQUAKE



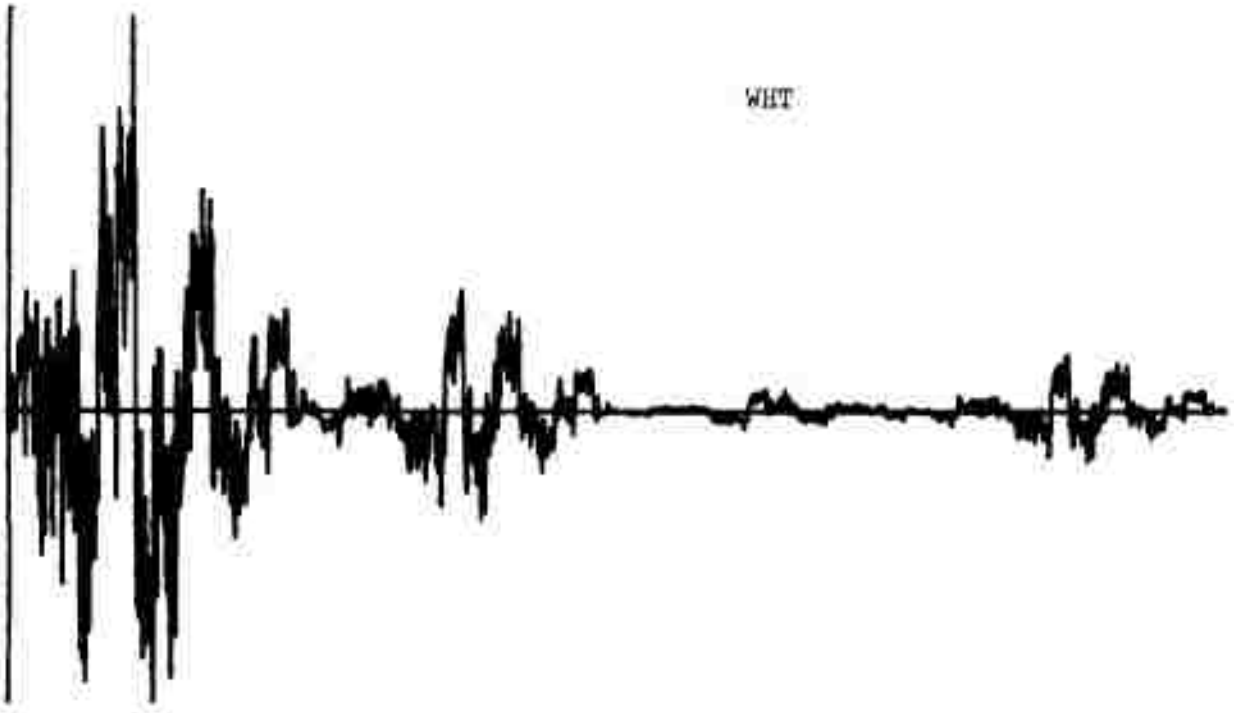
QC44

EVENT NUMBER 2028
EARTHQUAKE

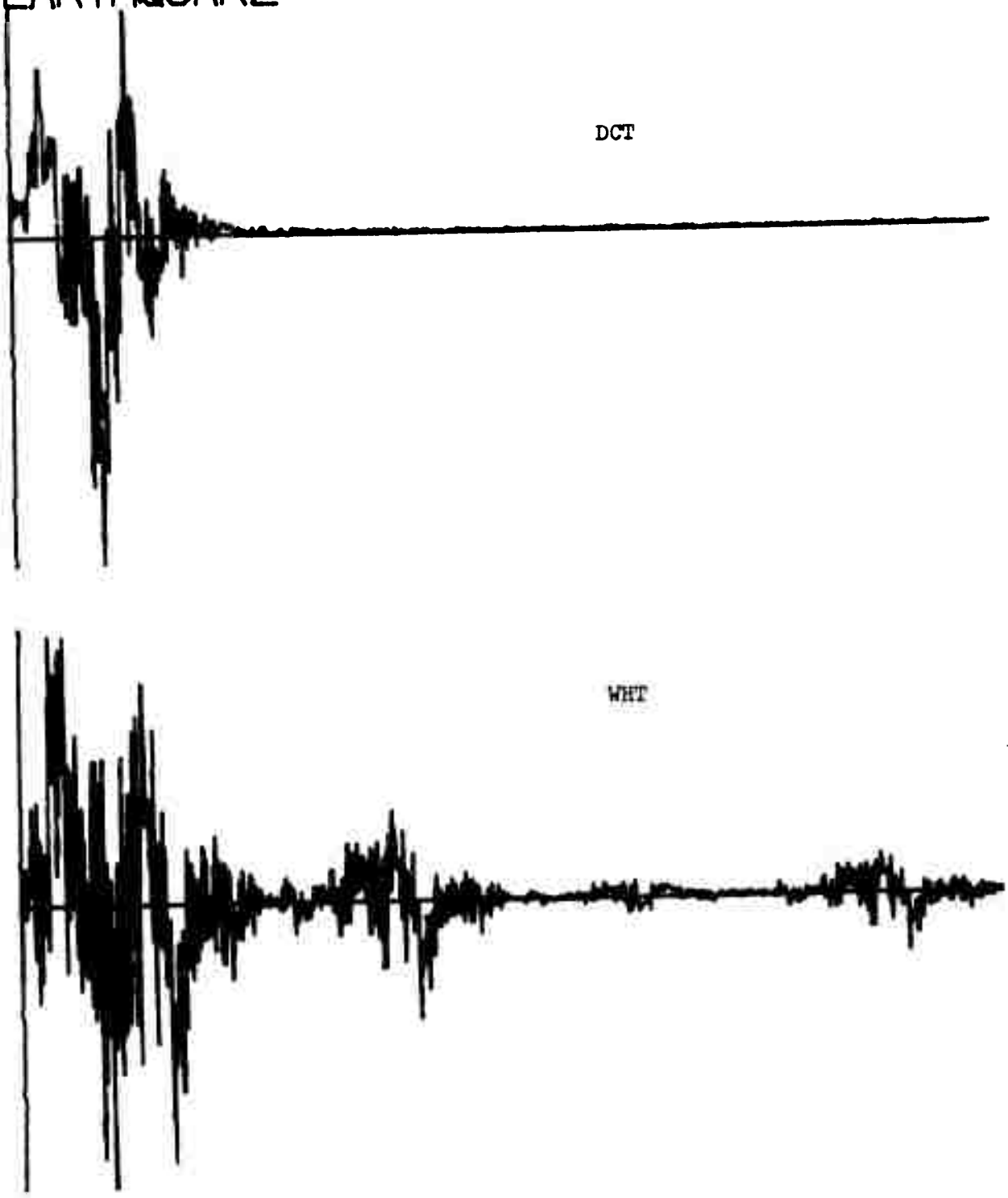
DCT



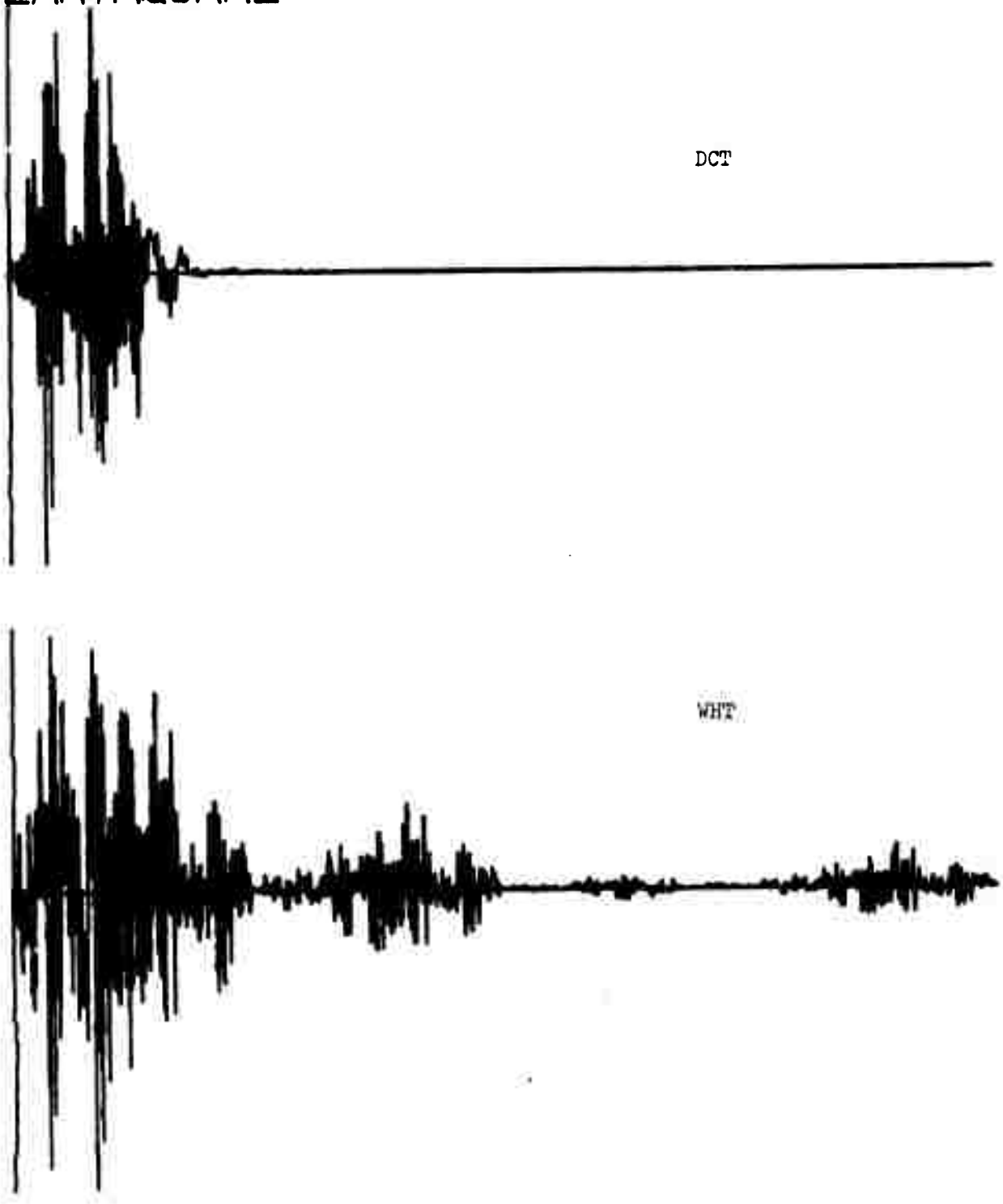
WHT



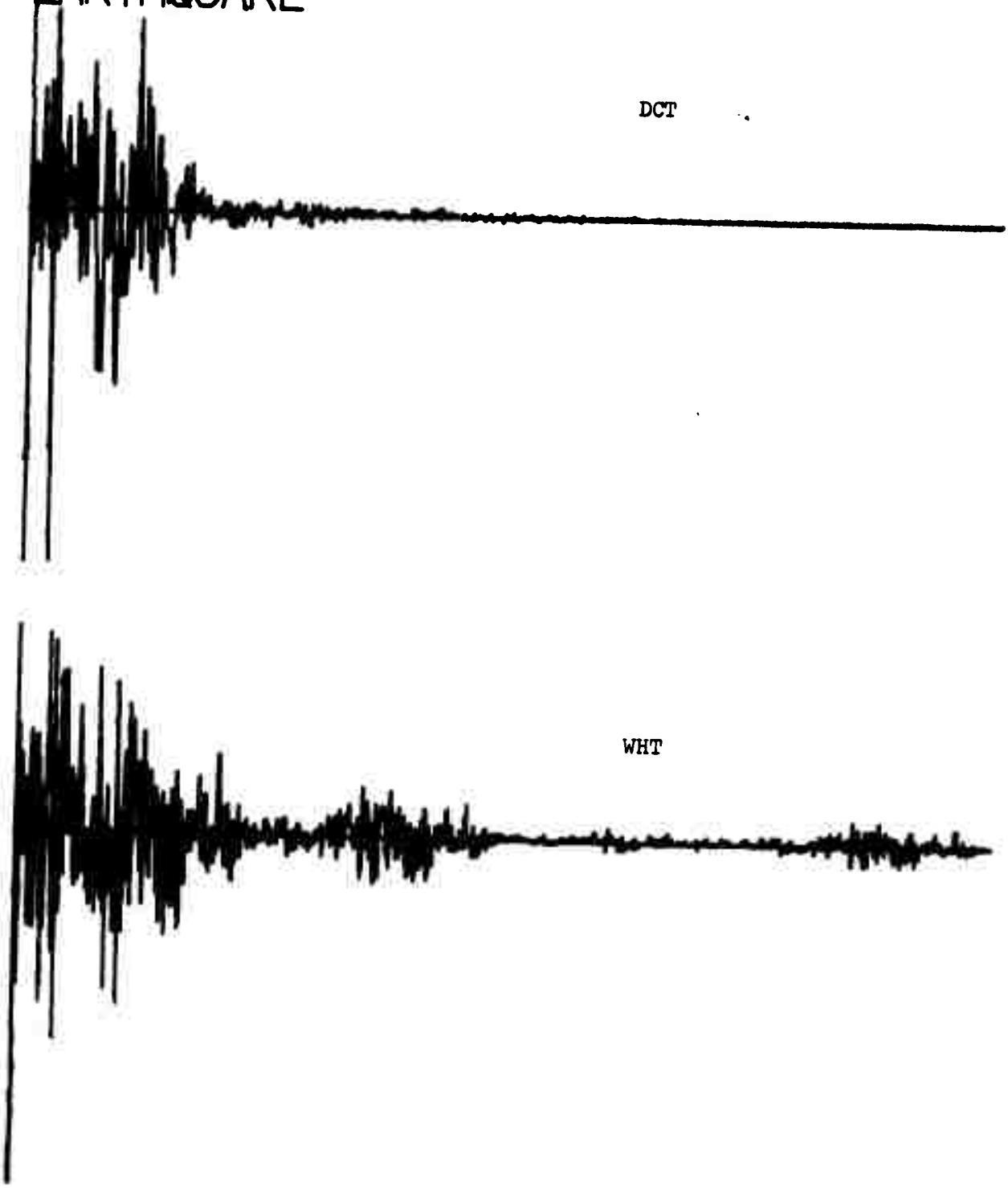
EVENT NUMBER 2Ø32
EARTHQUAKE



EVENT NUMBER 2033
EARTHQUAKE

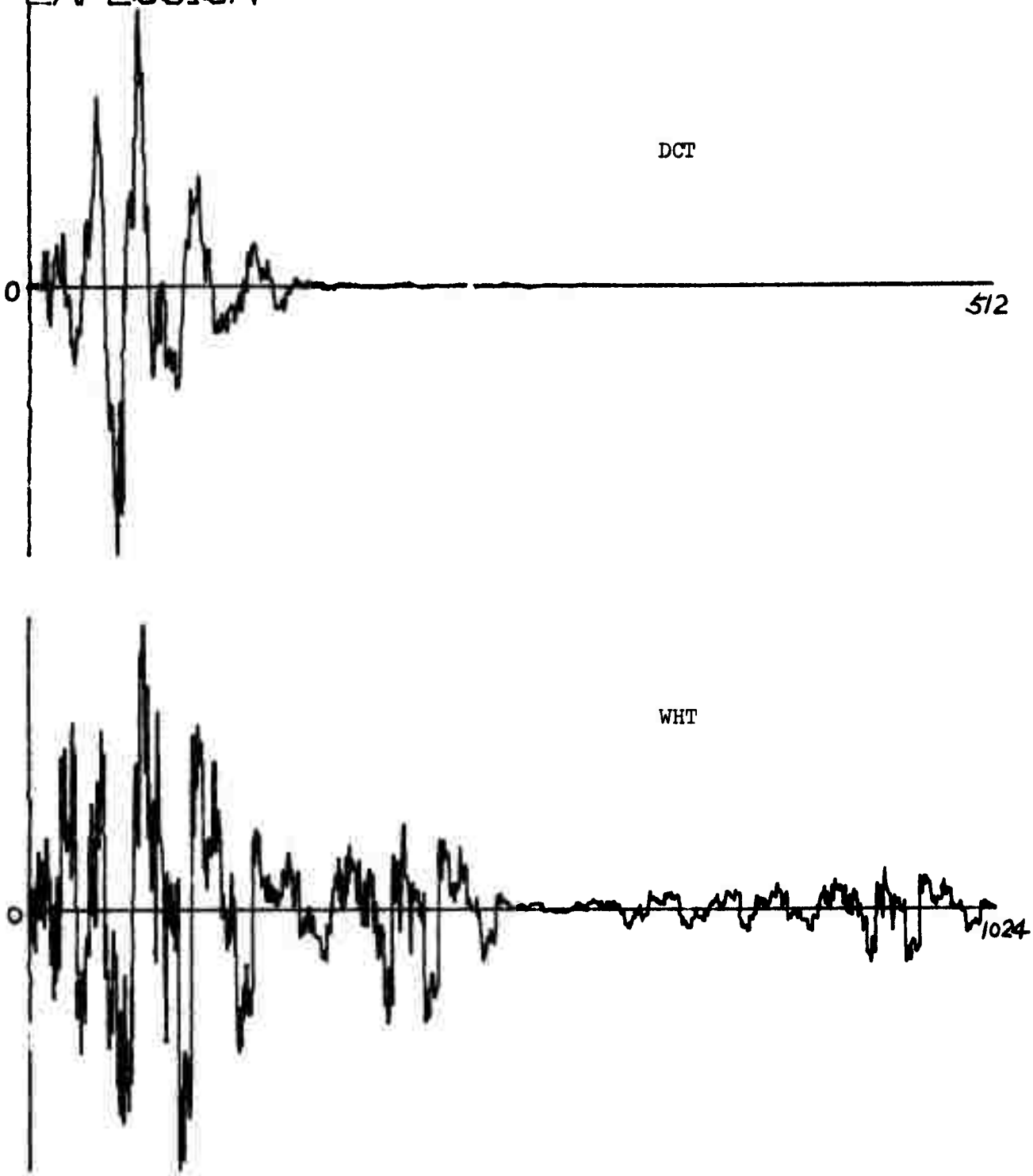


EVENT NUMBER 2034
EARTHQUAKE

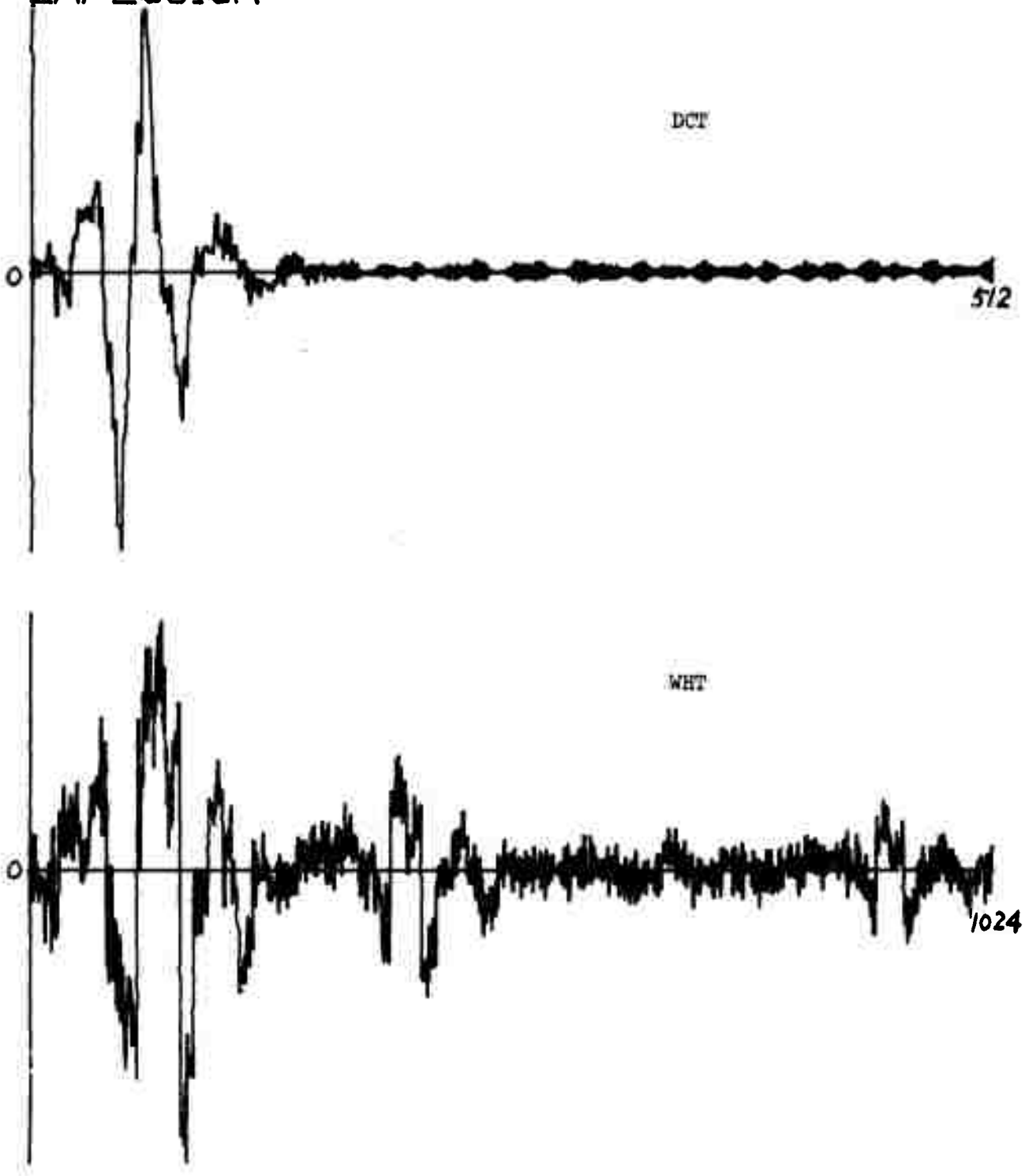


X052

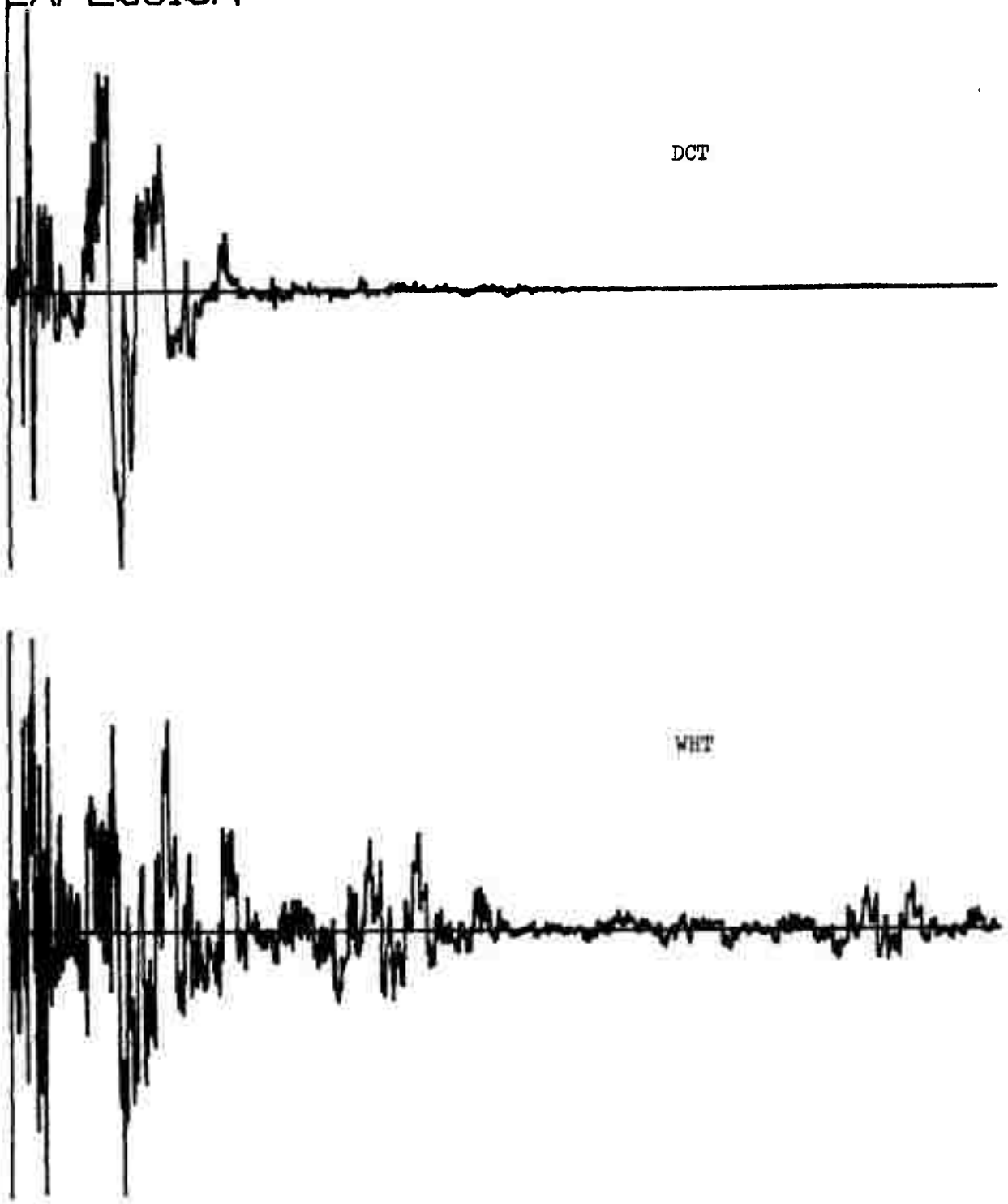
EVENT NUMBER 1507
EXPLOSION



EVENT NUMBER 1531
EXPLOSION



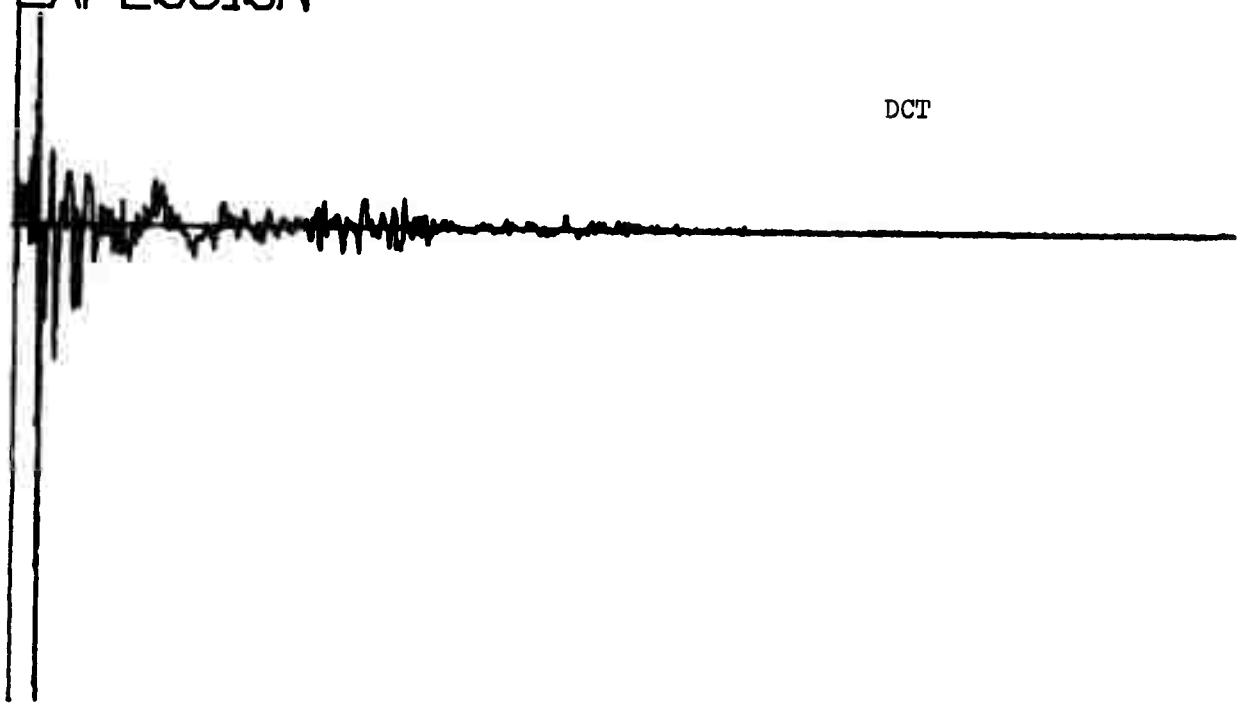
EVENT NUMBER 1512
EXPLOSION



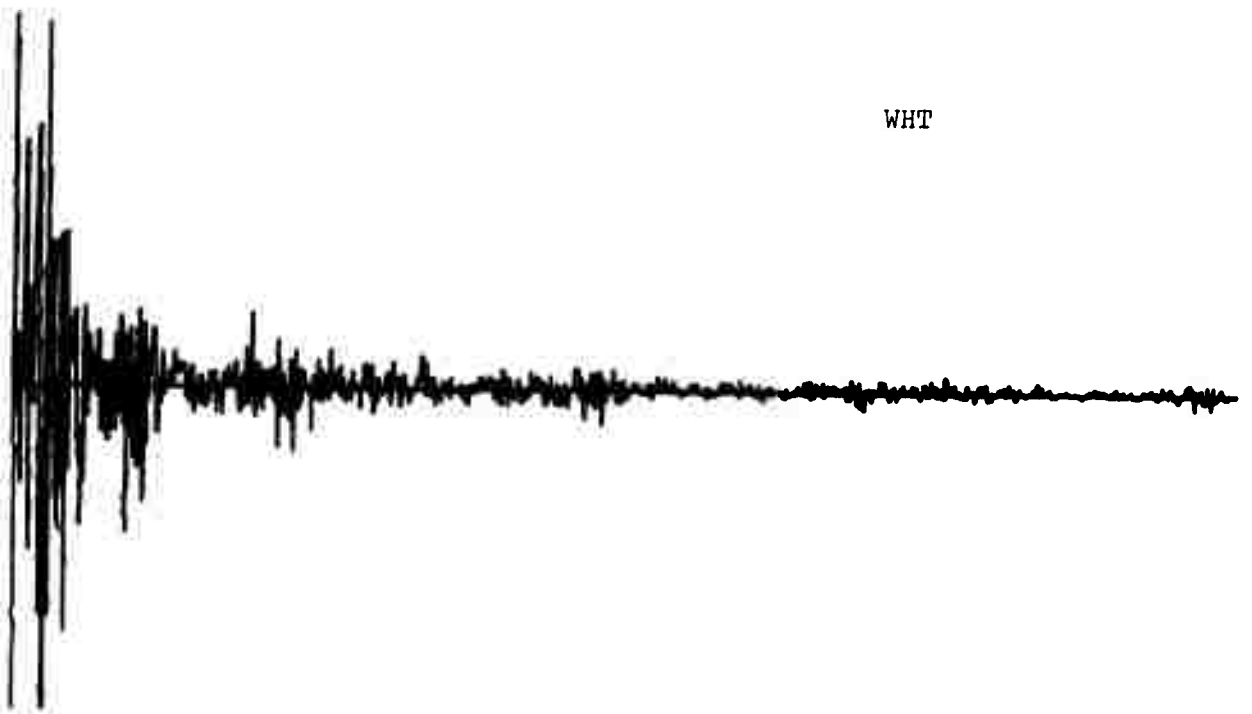
X058

EVENT NUMBER 1525
EXPLOSION

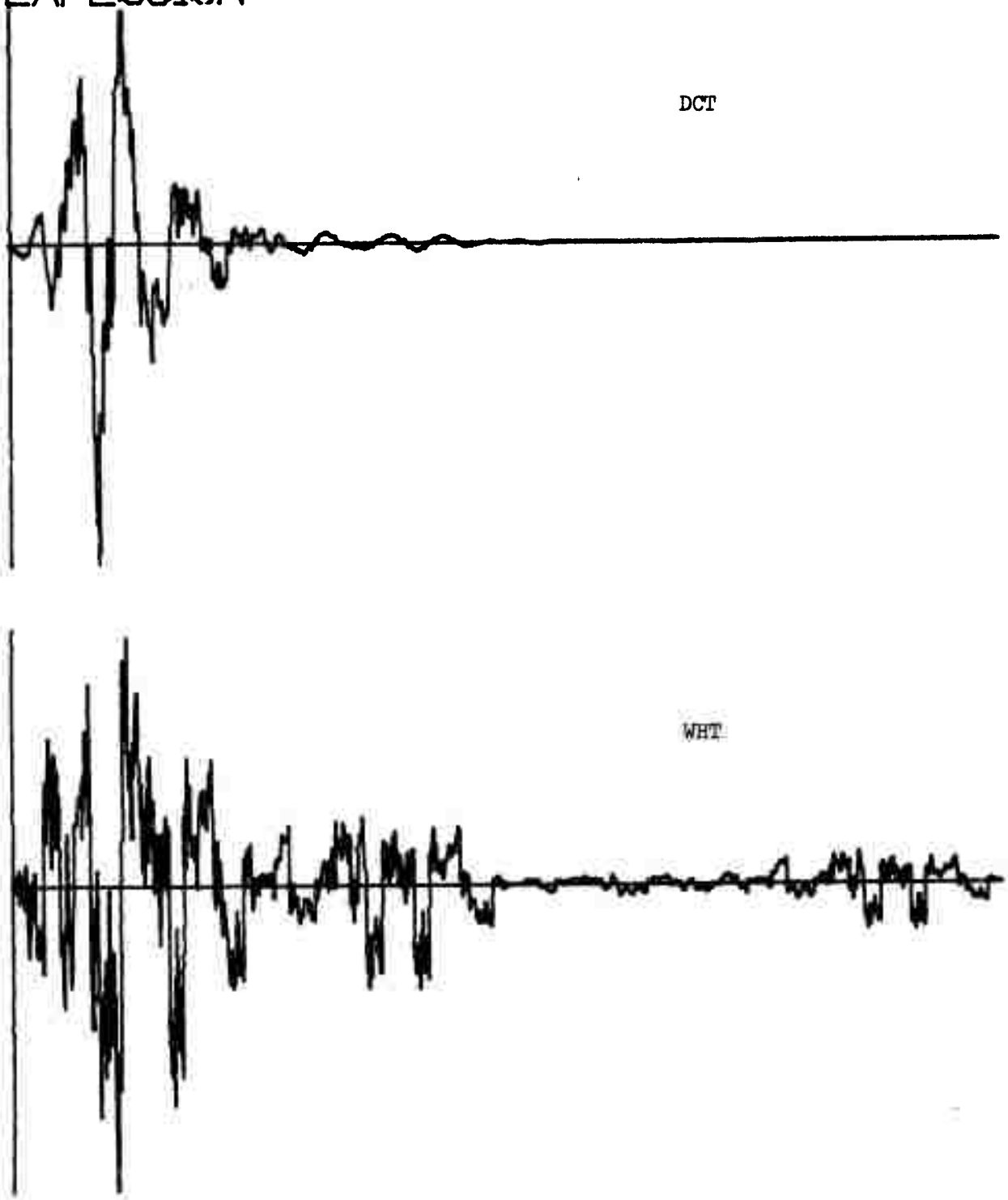
DCT



WHT

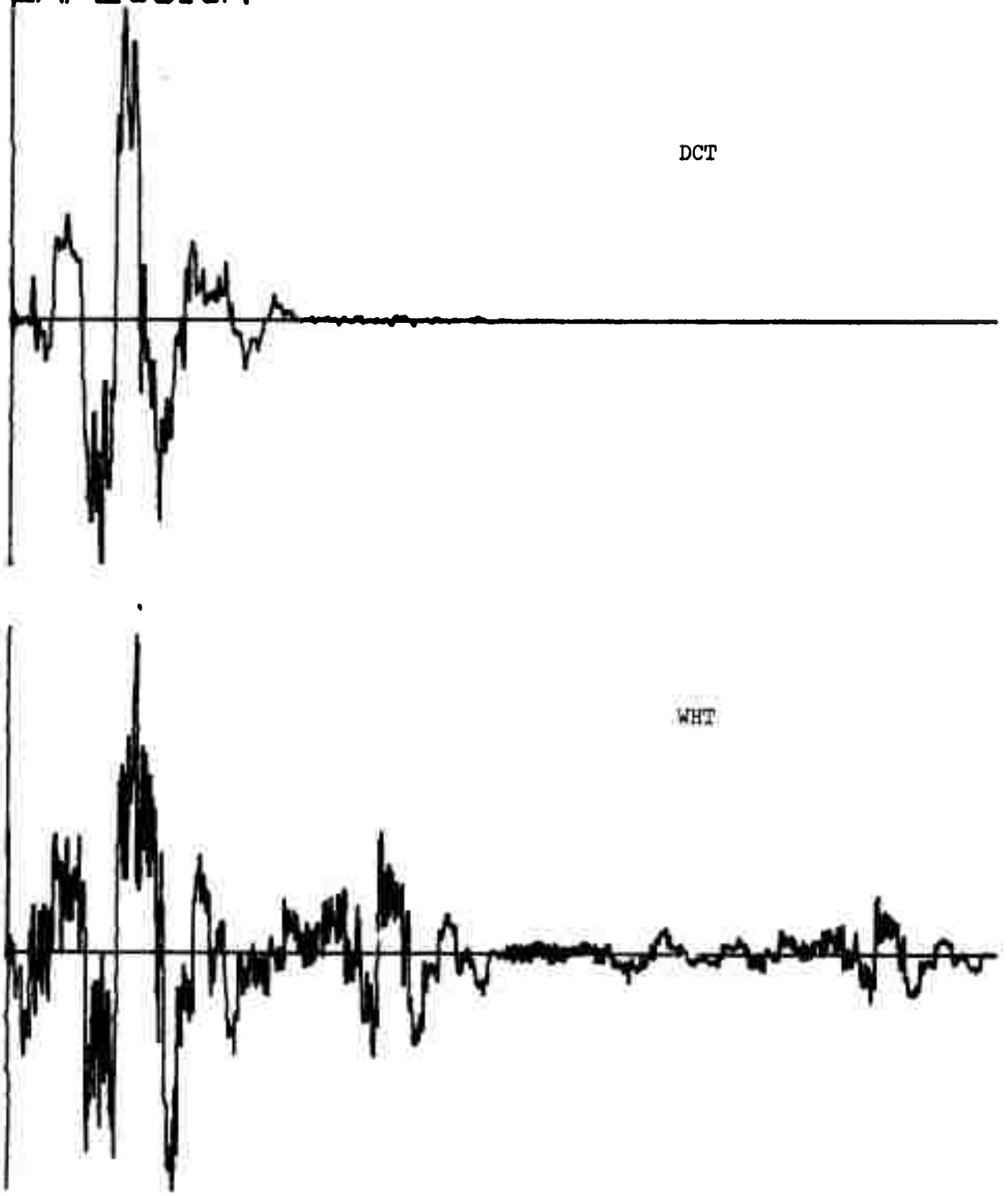


EVENT NUMBER 1518
EXPLOSION

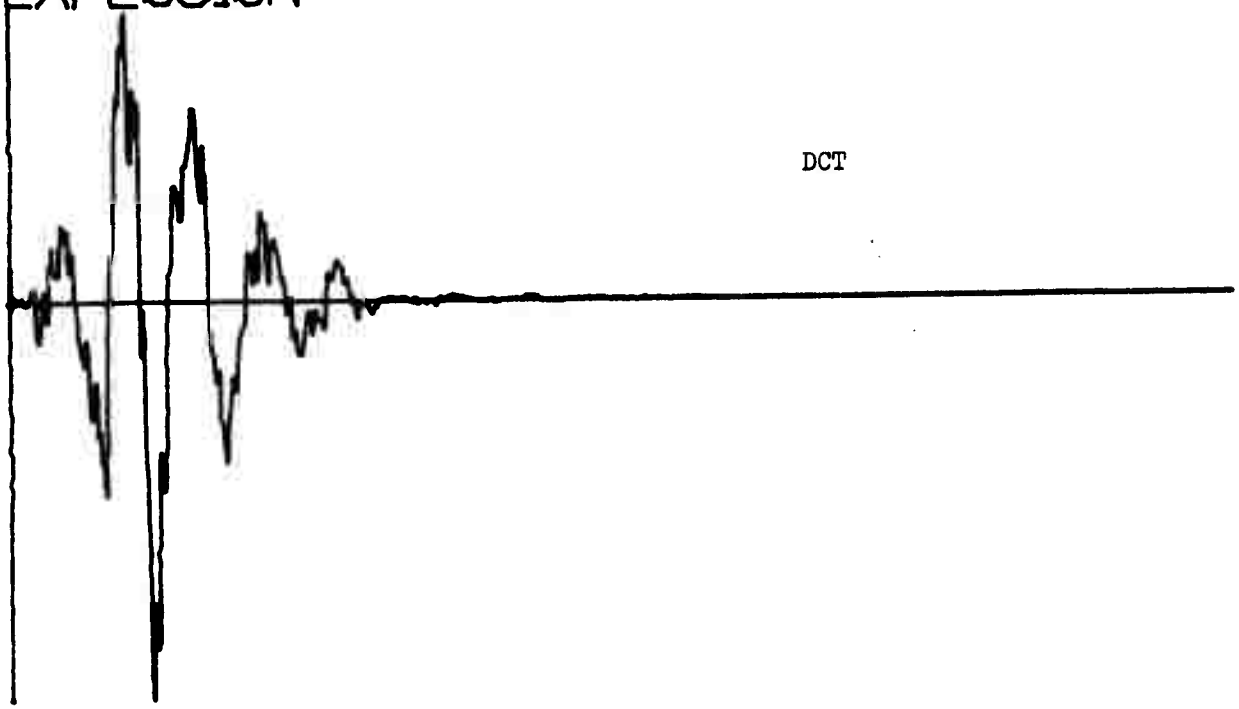


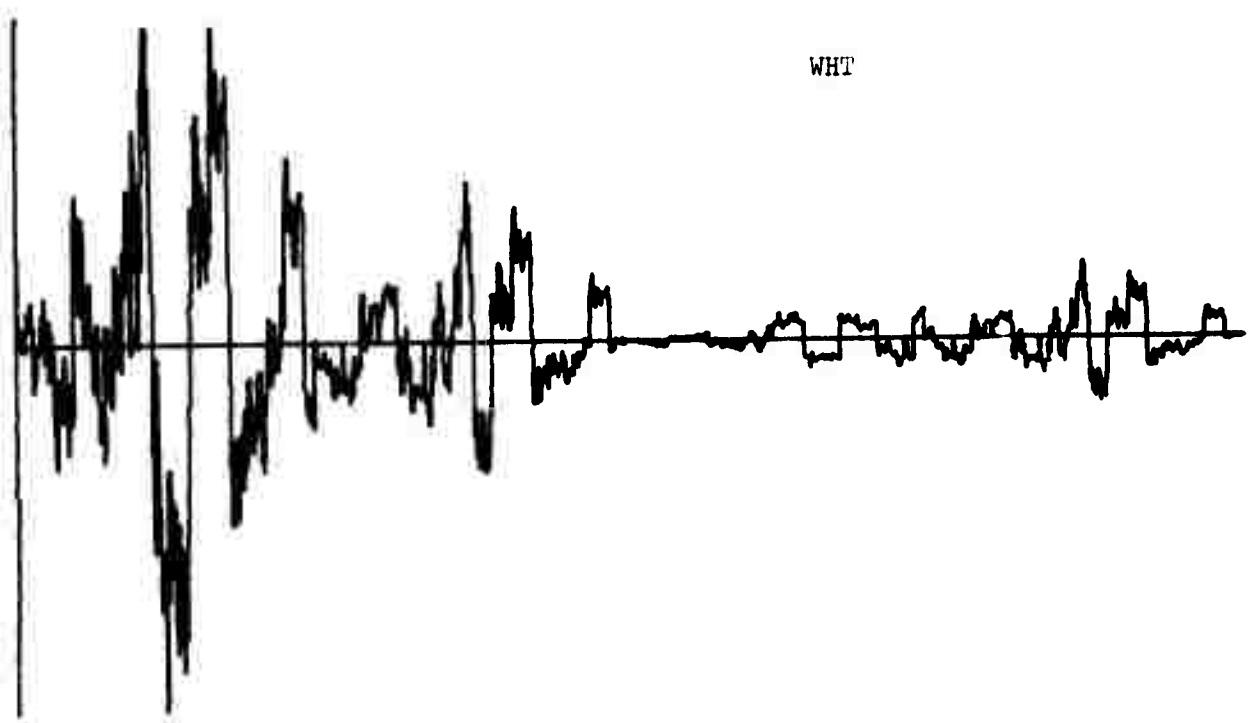
X062

EVENT NUMBER 1514
EXPLOSION



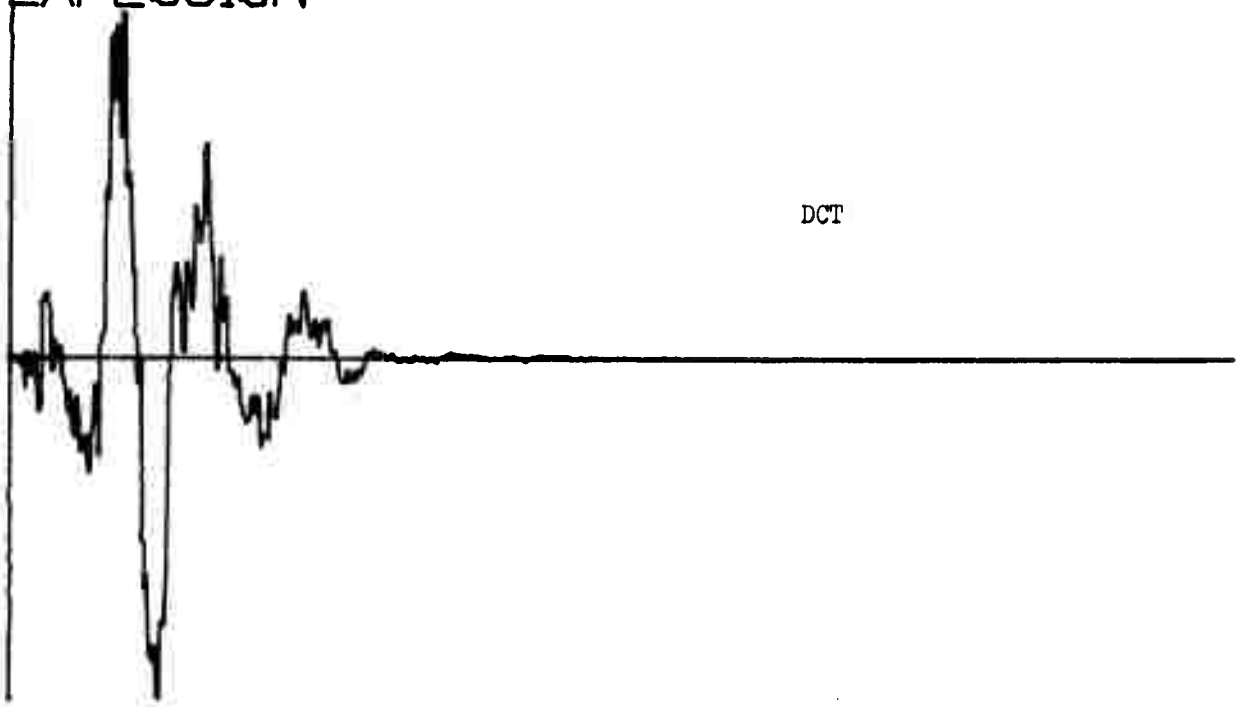
EVENT NUMBER 1513
EXPLOSION

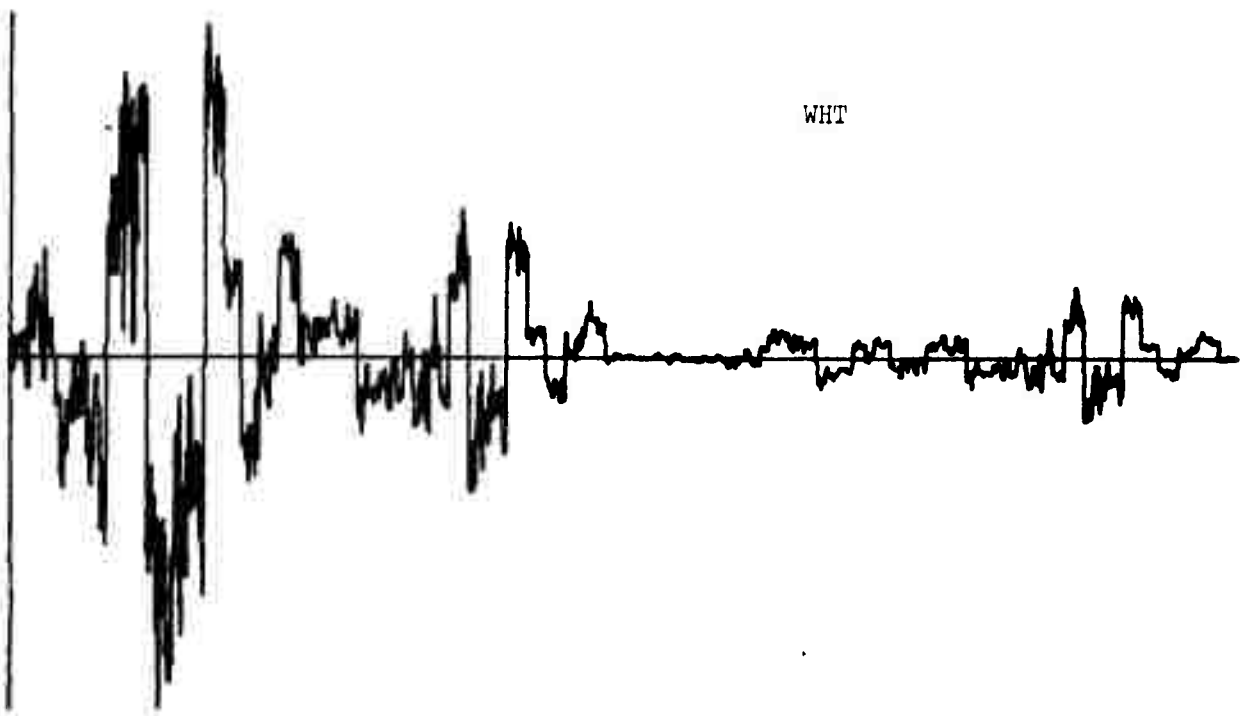




X066

EVENT NUMBER 1511
EXPLOSION

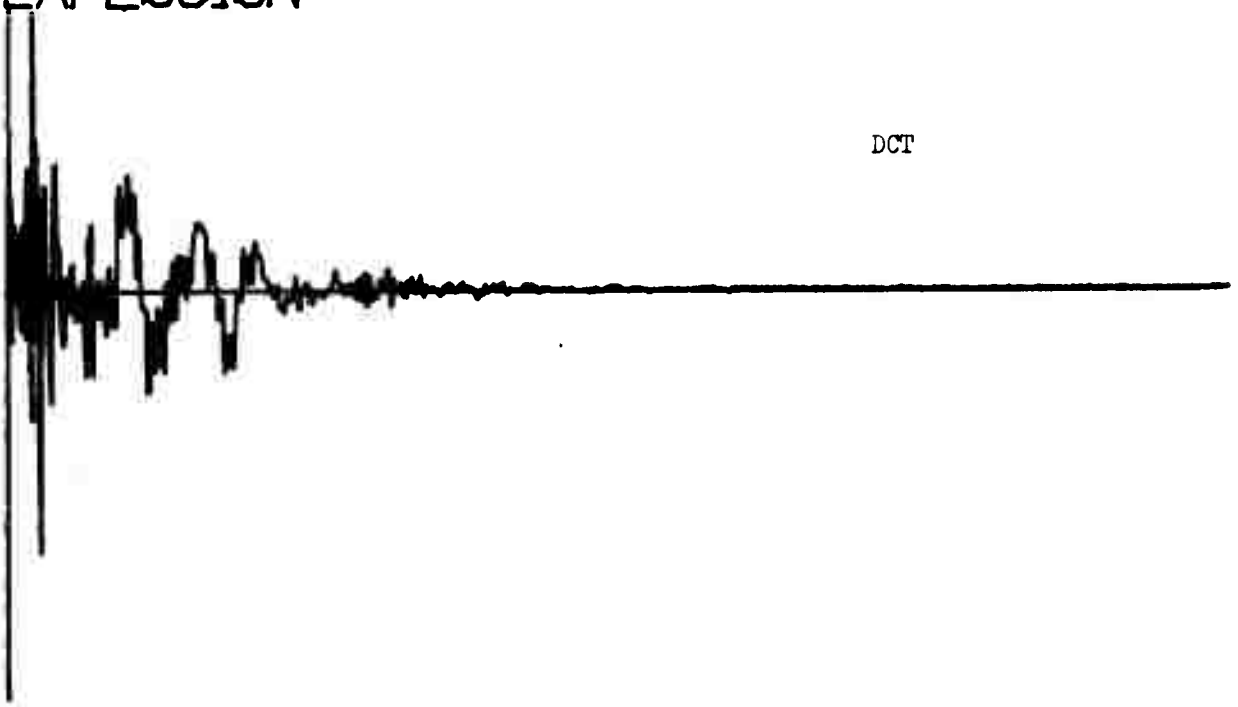




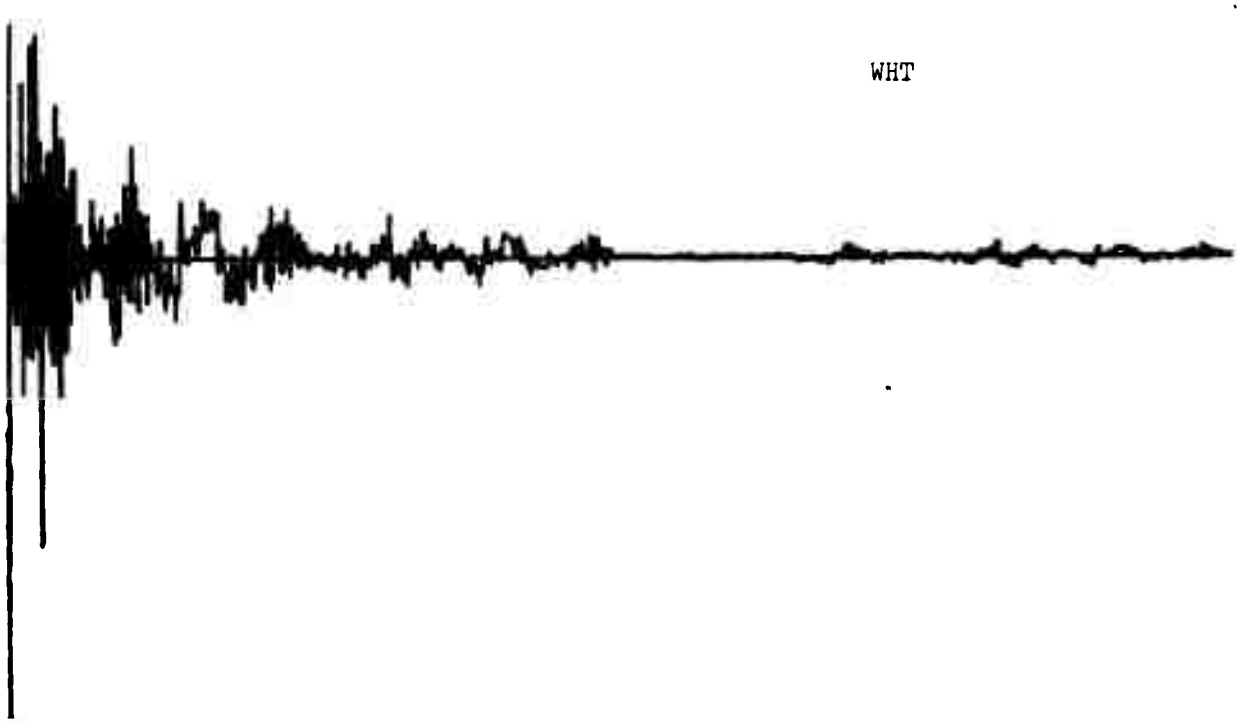
X068

EVENT NUMBER 1532
EXPLOSION

DCT

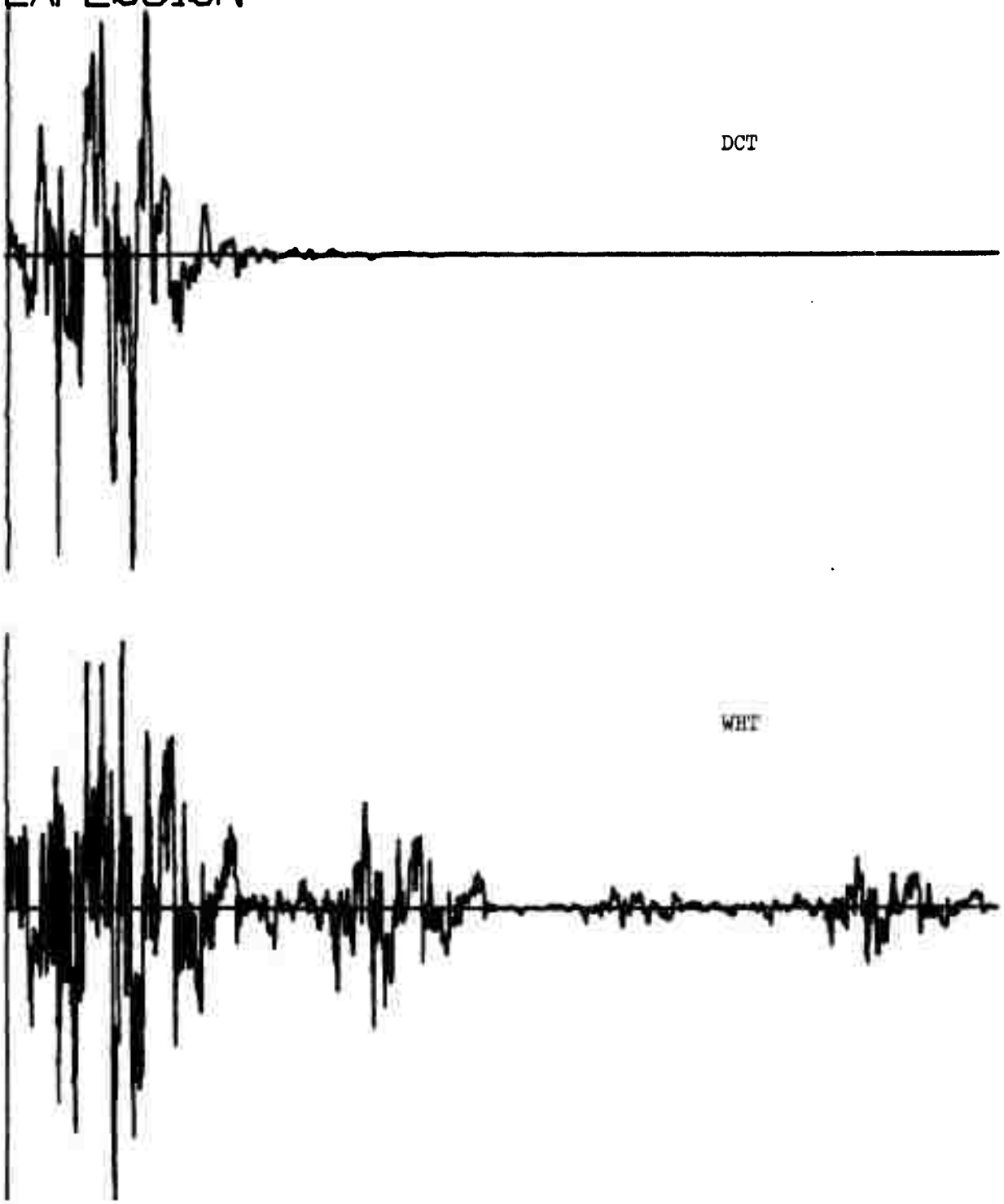


WHT



X070

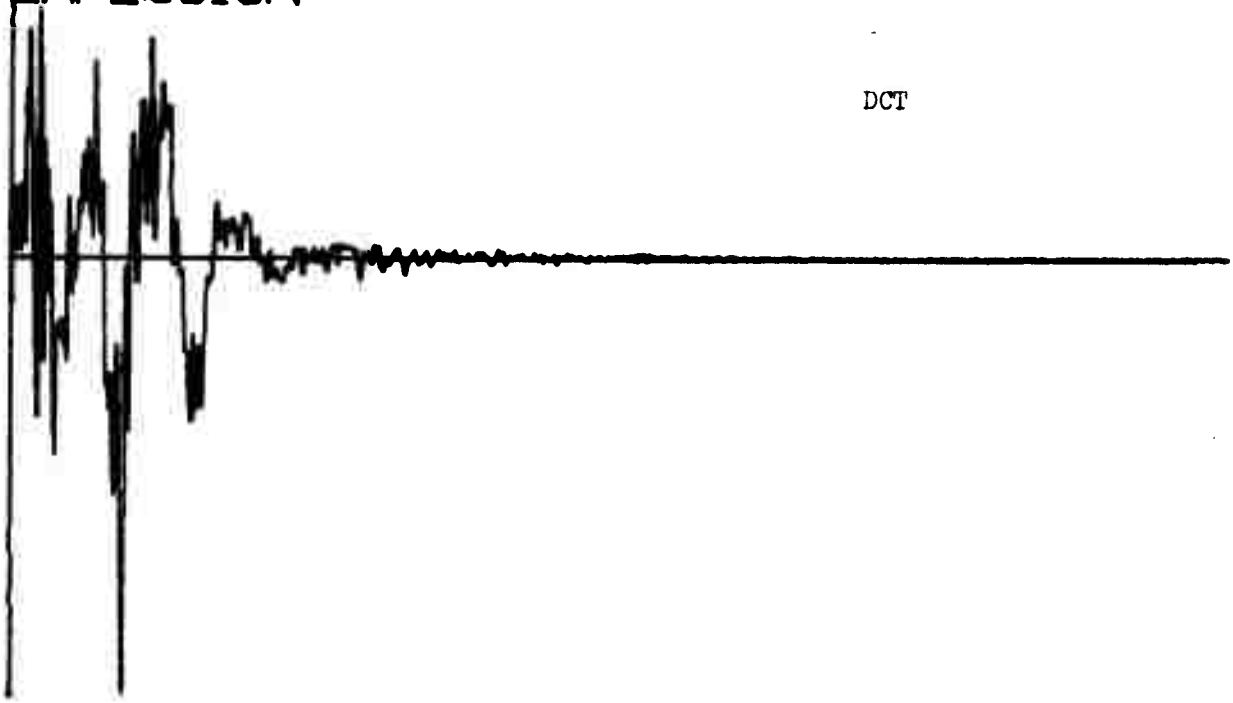
EVENT NUMBER 1530
EXPLOSION



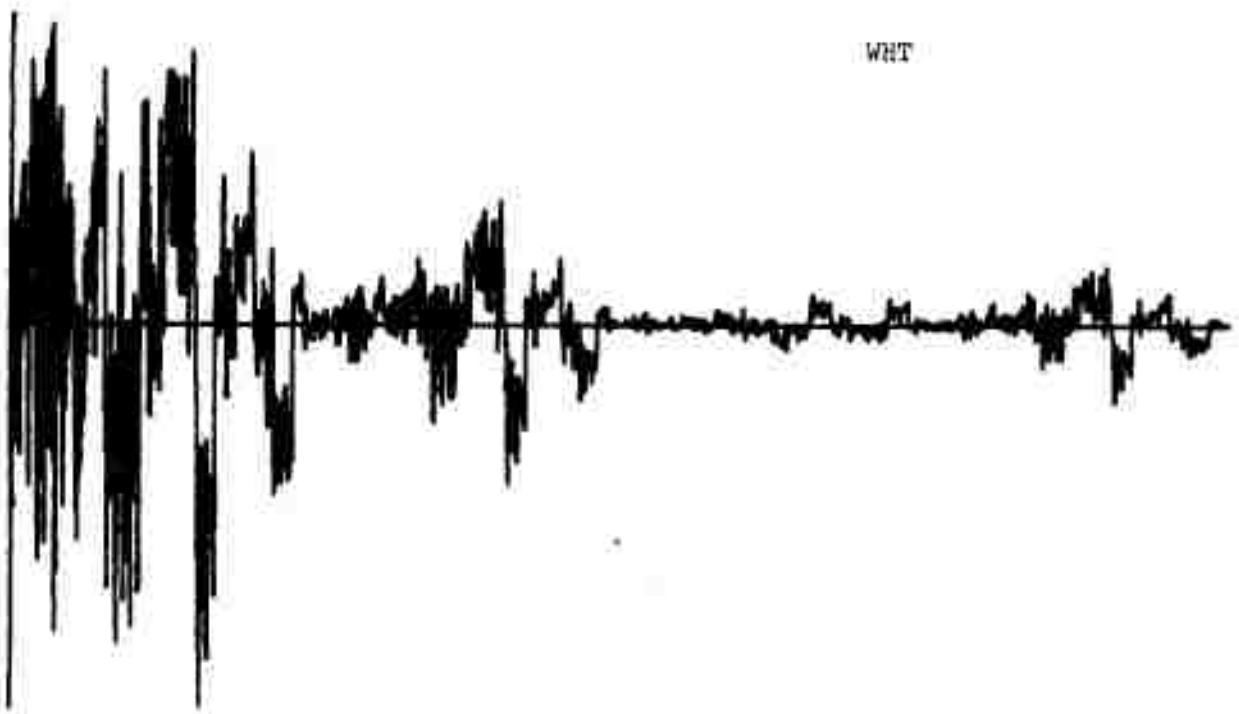
X072

EVENT NUMBER 1528
EXPLOSION

DCT

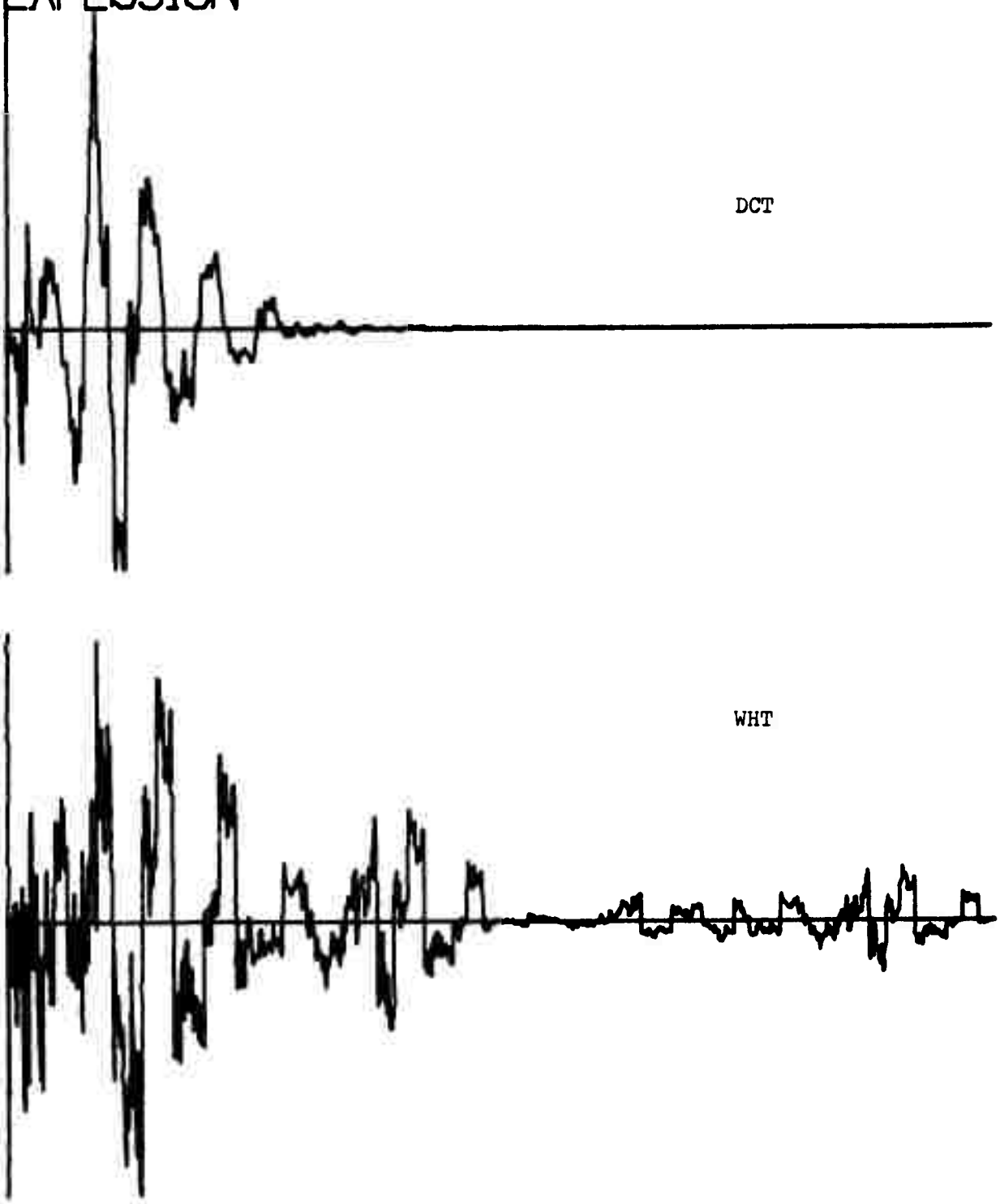


WHT

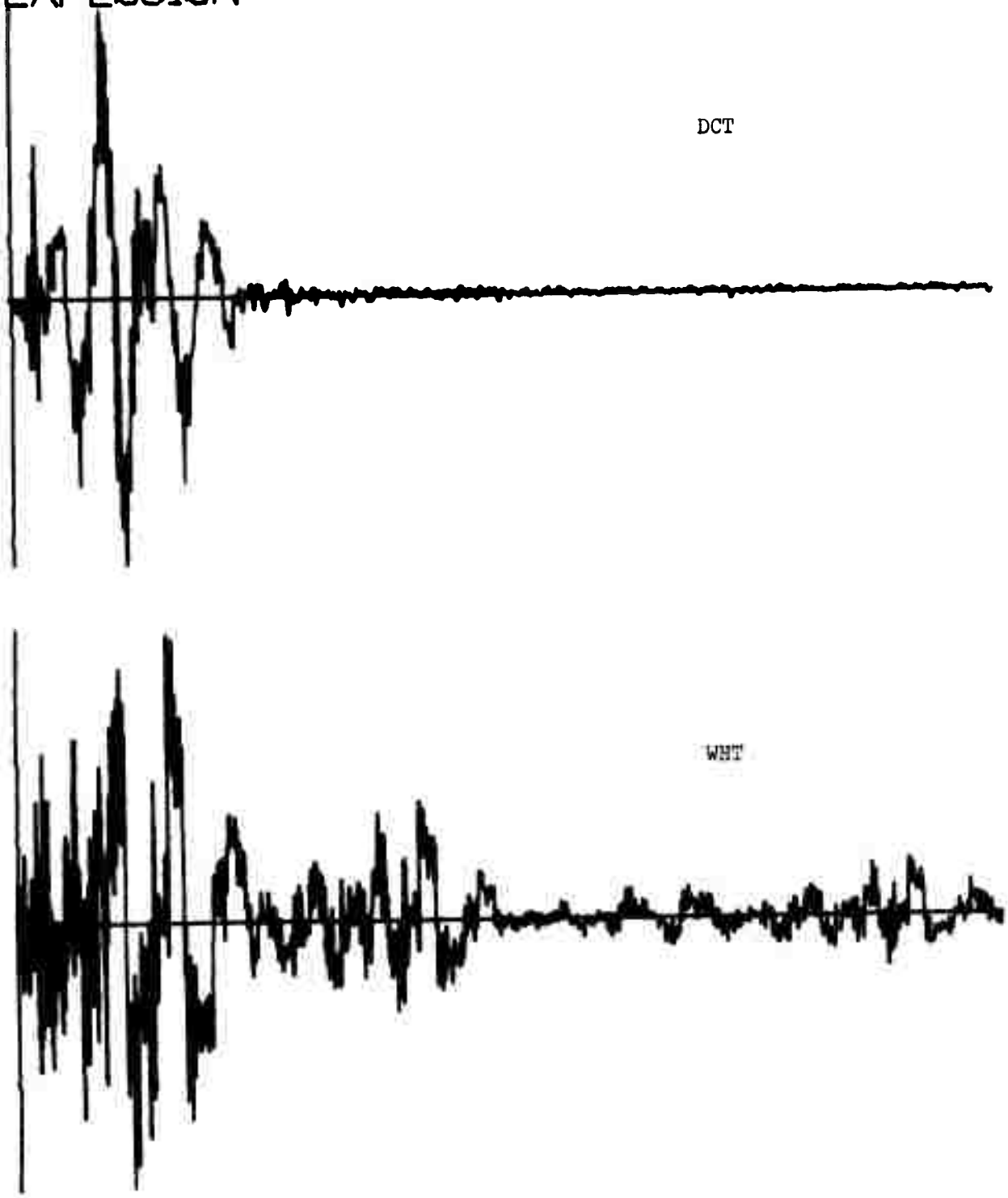


X074

EVENT NUMBER 1540
EXPLOSION

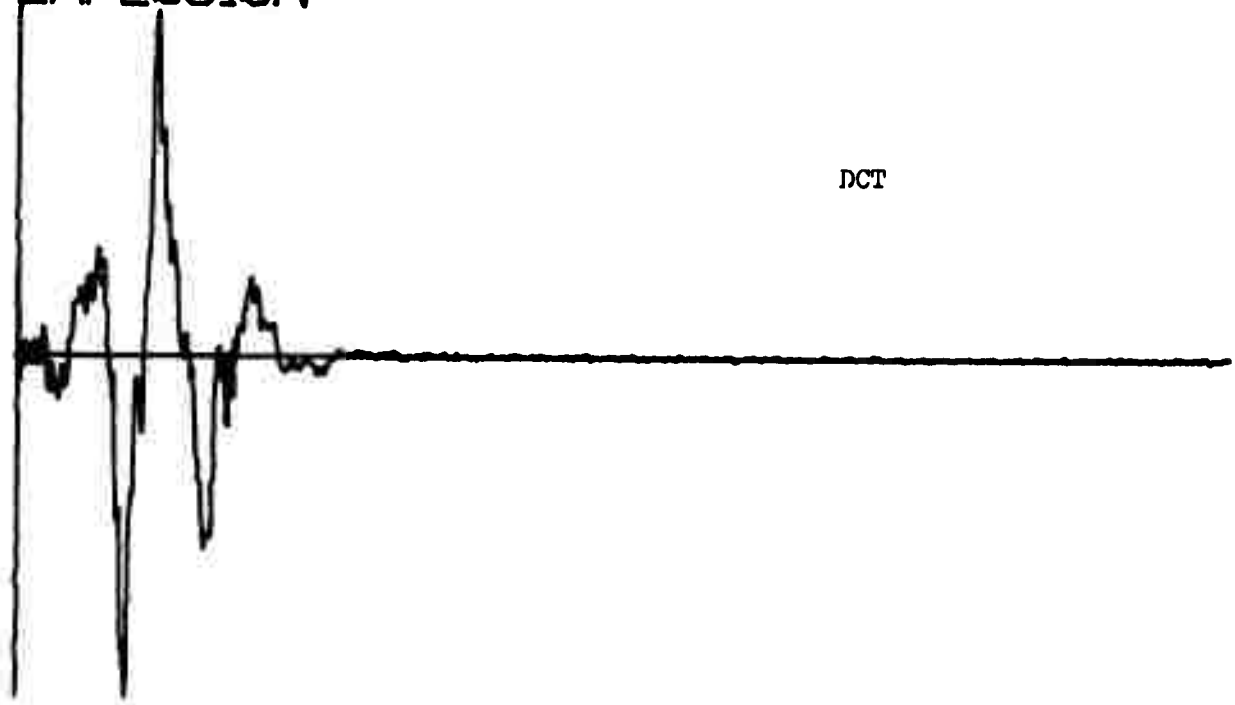


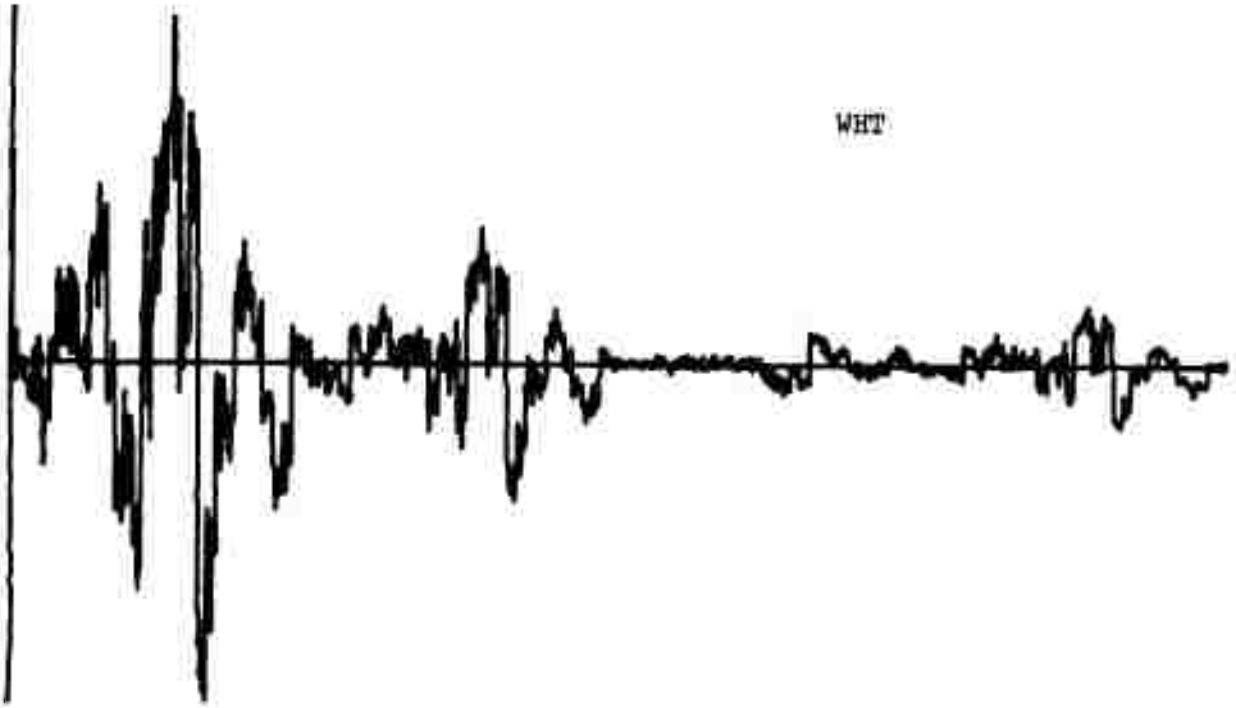
EVENT NUMBER 1527
EXPLOSION



X078

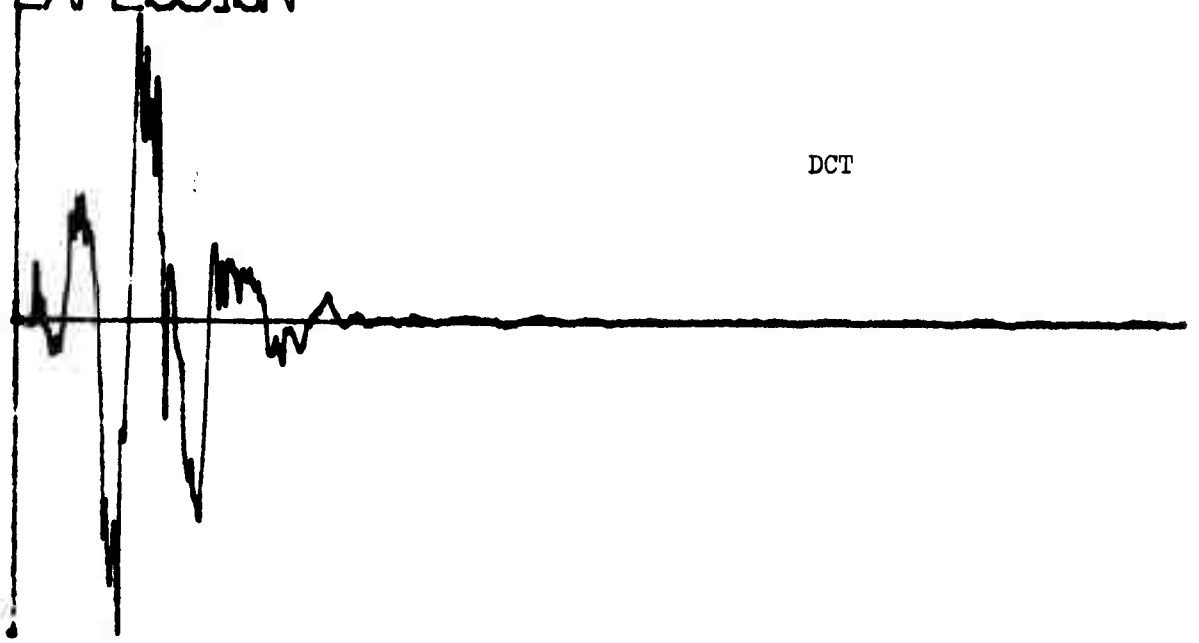
EVENT NUMBER 1524
EXPLOSION

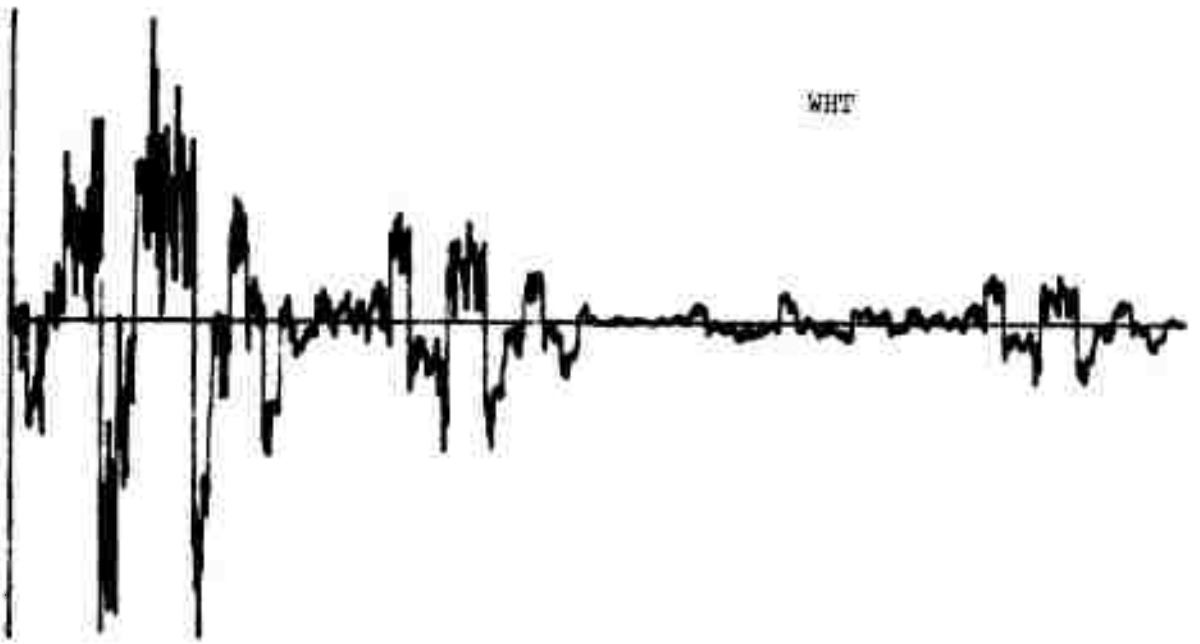




X080

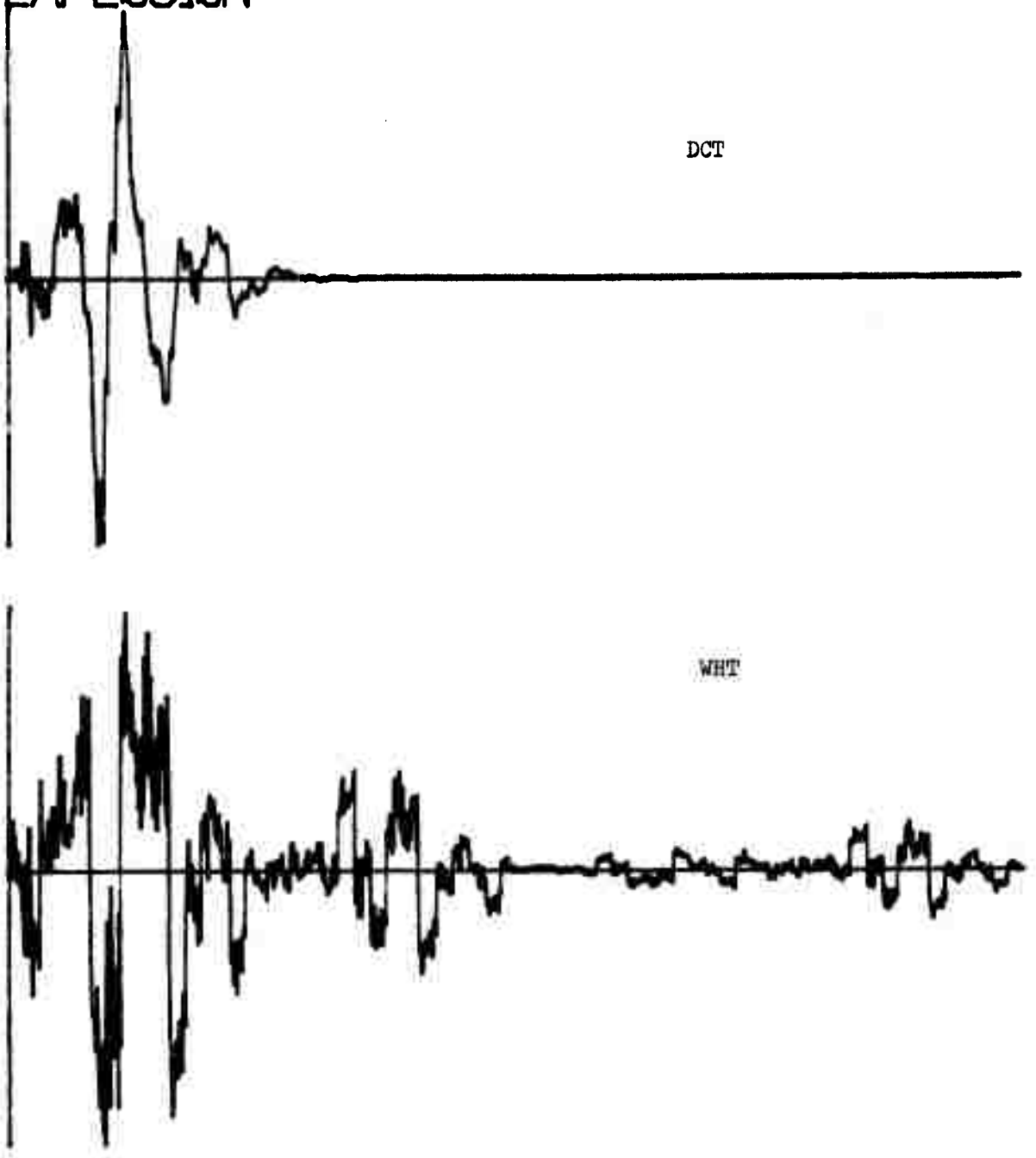
EVENT NUMBER 1521
EXPLOSION





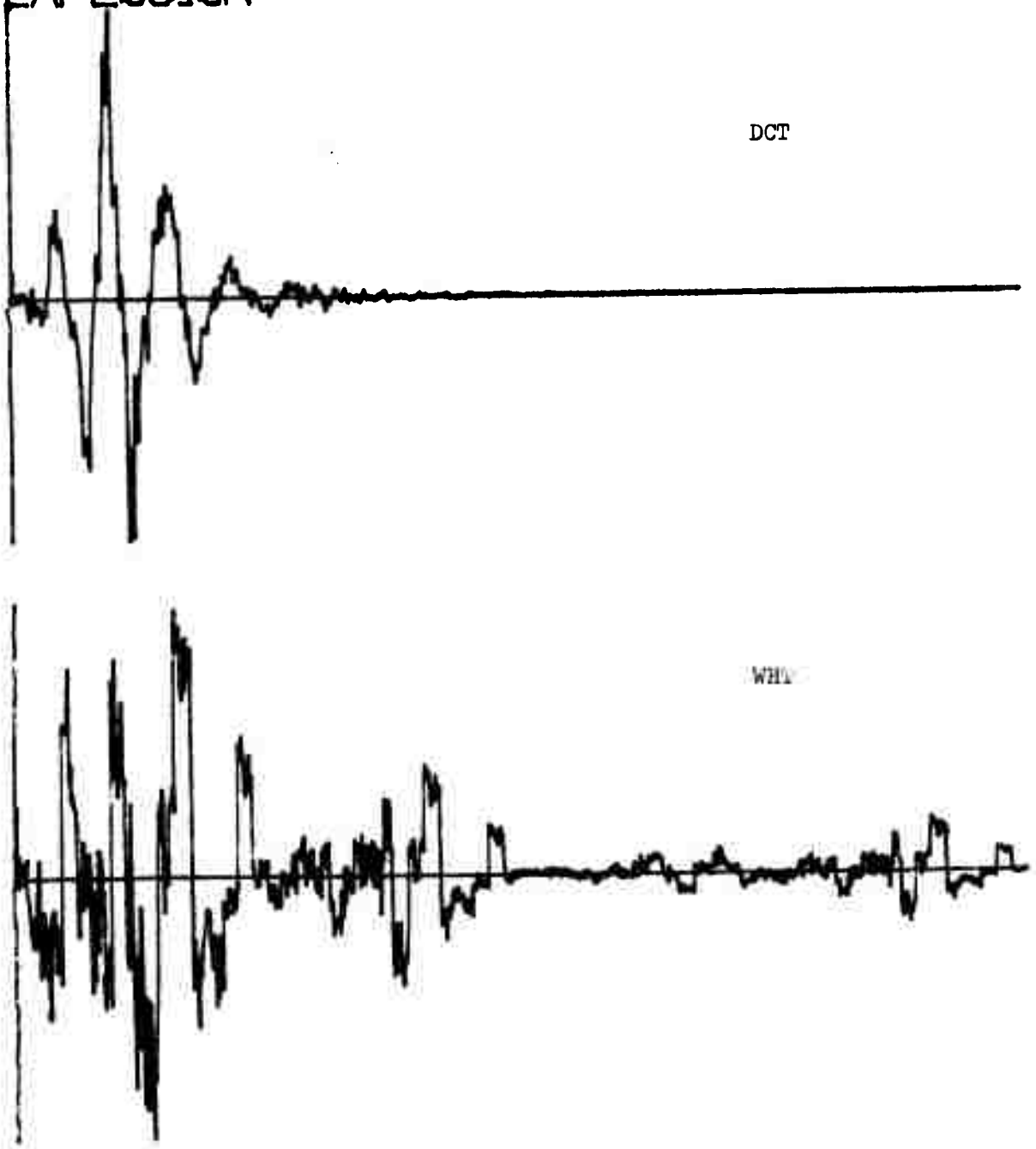
X082

EVENT NUMBER 1504
EXPLOSION

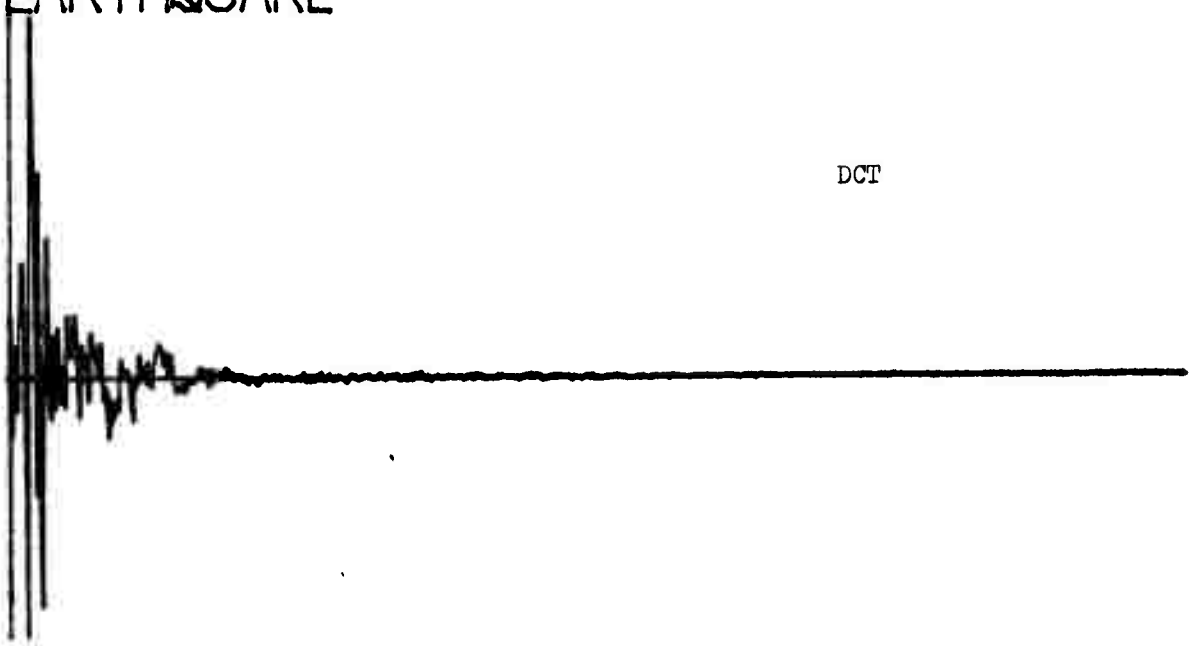


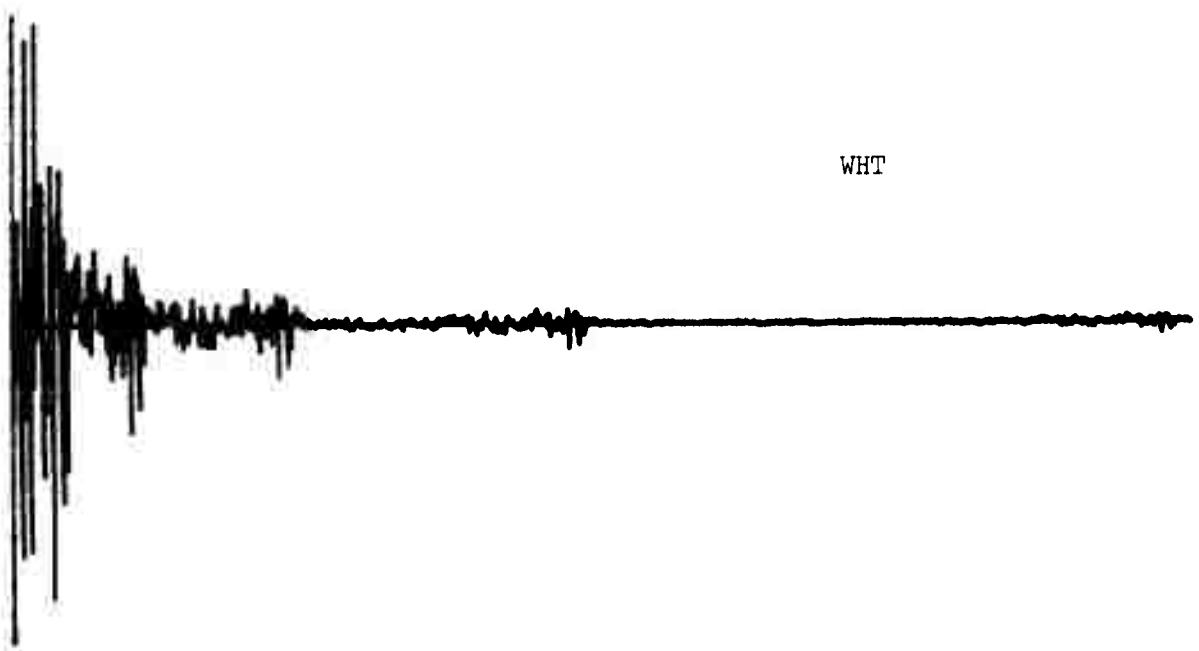
X084

EVENT NUMBER 1522
EXPLOSION



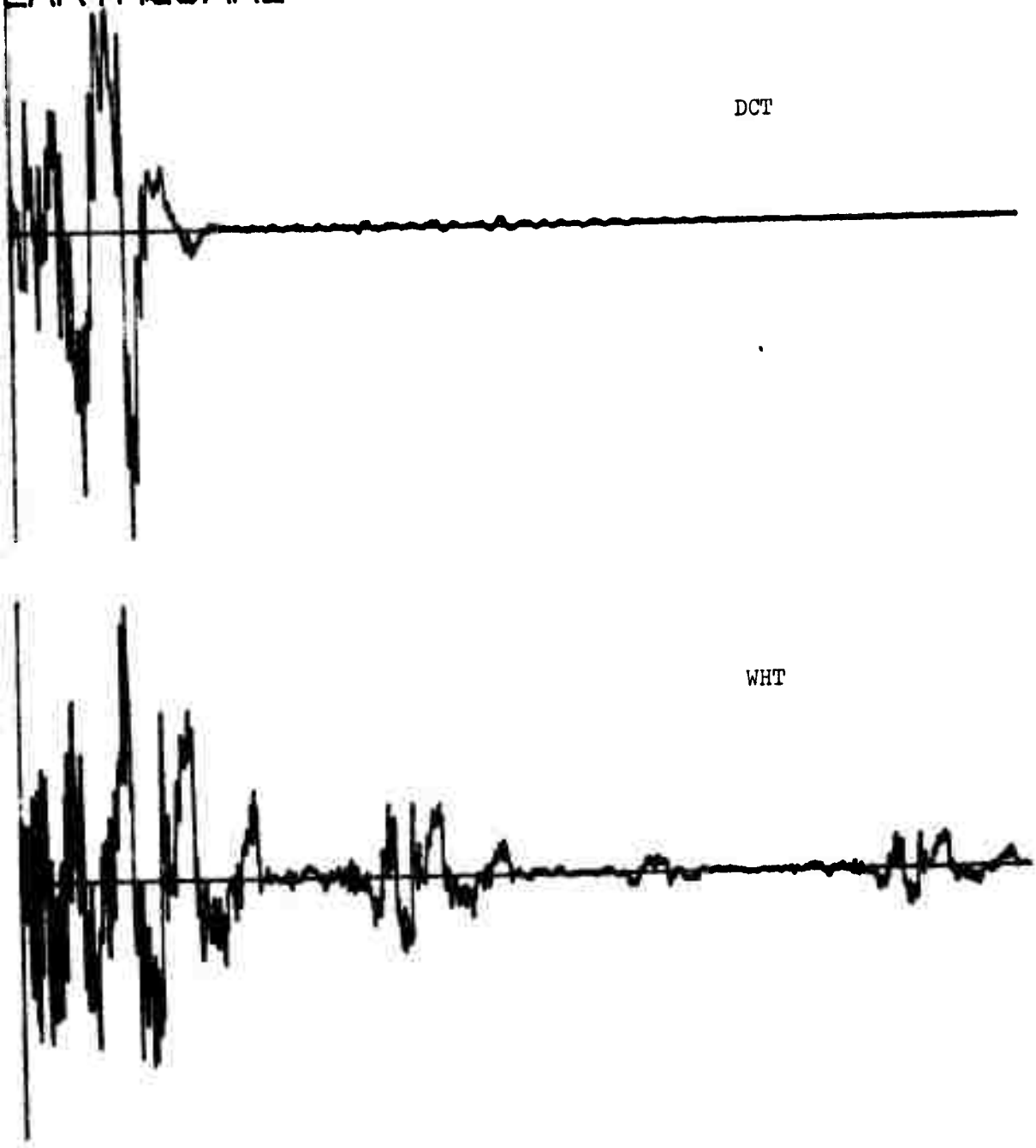
EVENT NUMBER 1008
EARTHQUAKE





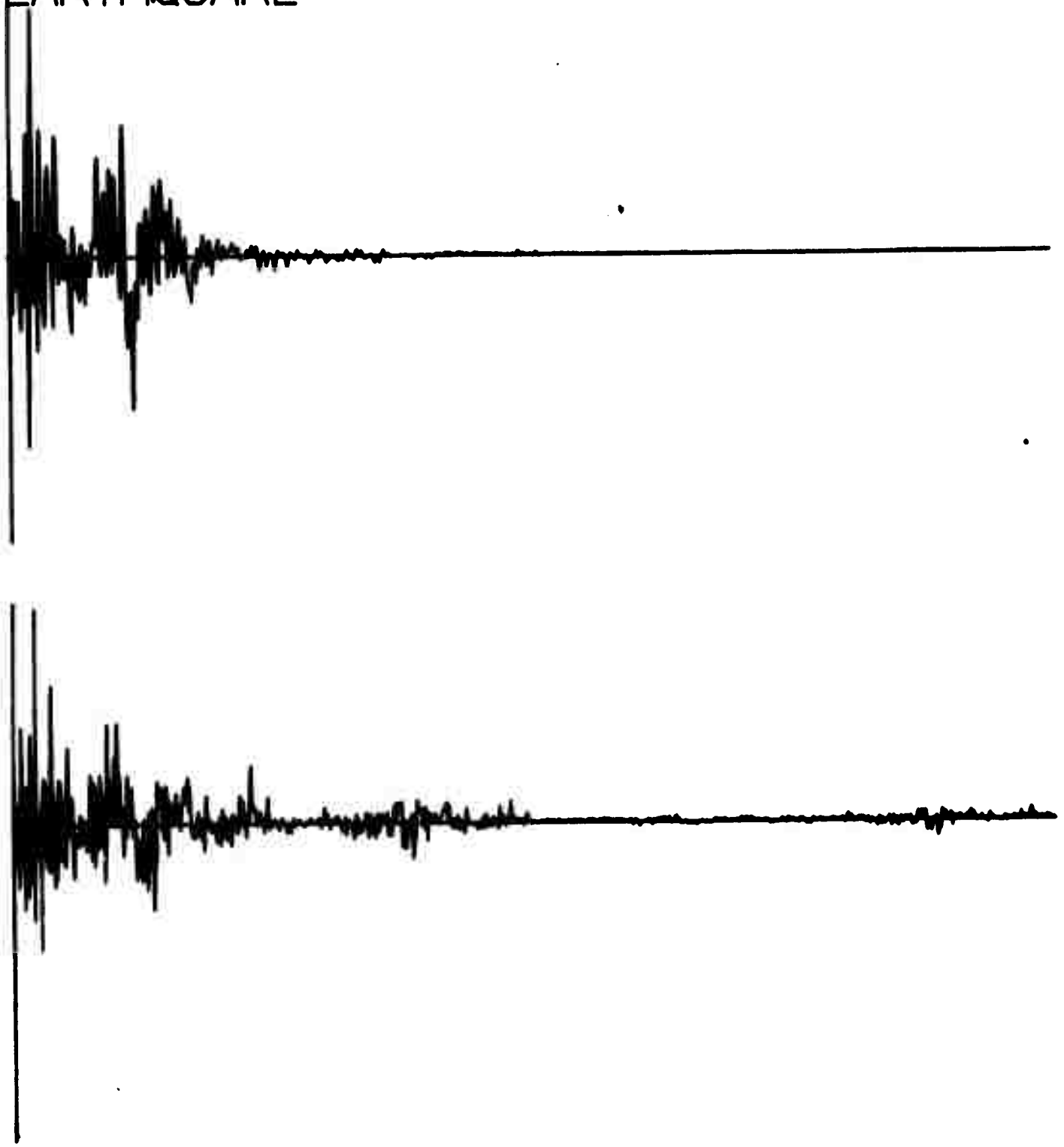
Q088

EVENT NUMBER 1009
EARTHQUAKE

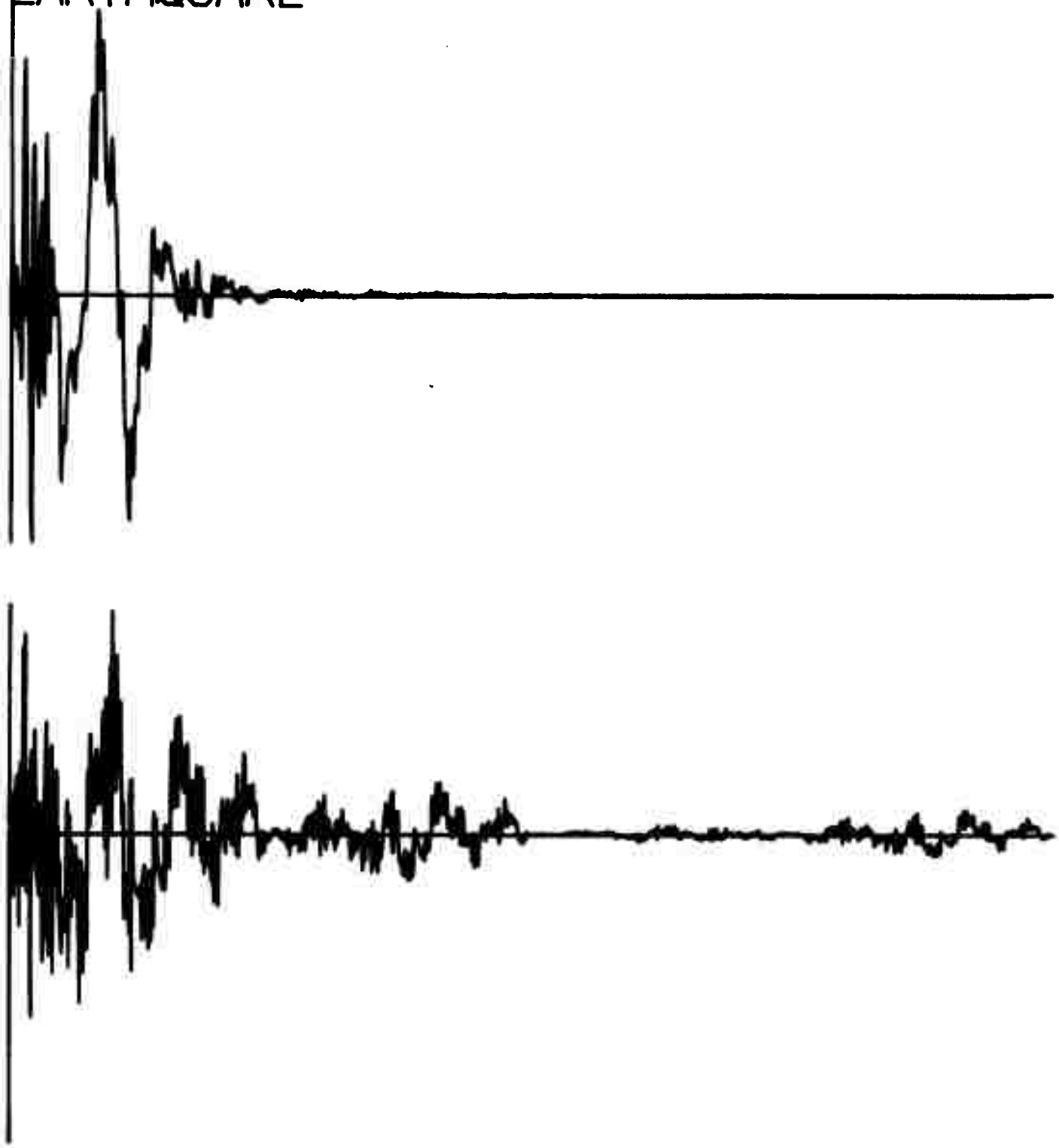


Q090

EVENT NUMBER 1011
EARTHQUAKE

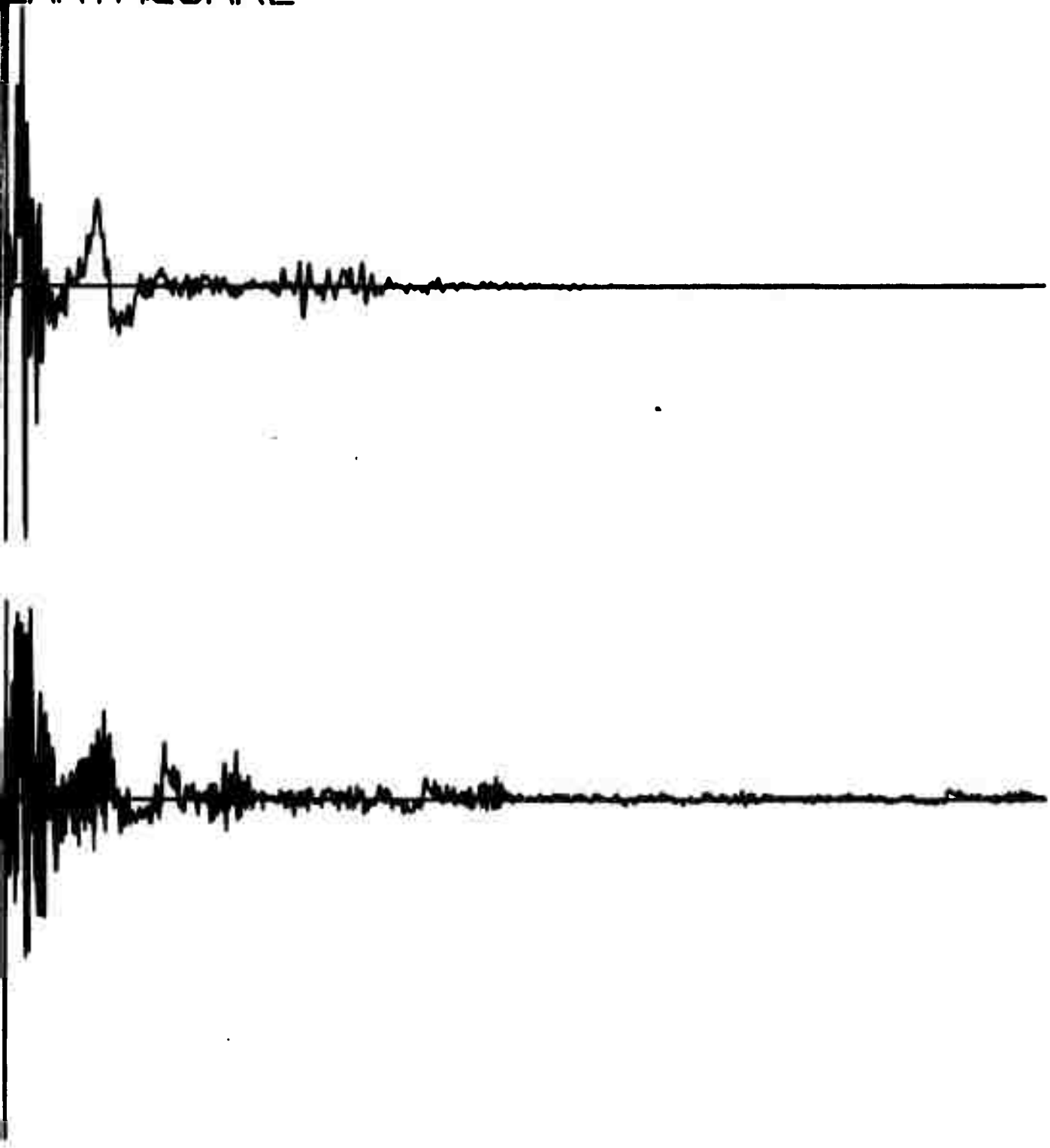


EVENT NUMBER 1023
EARTHQUAKE



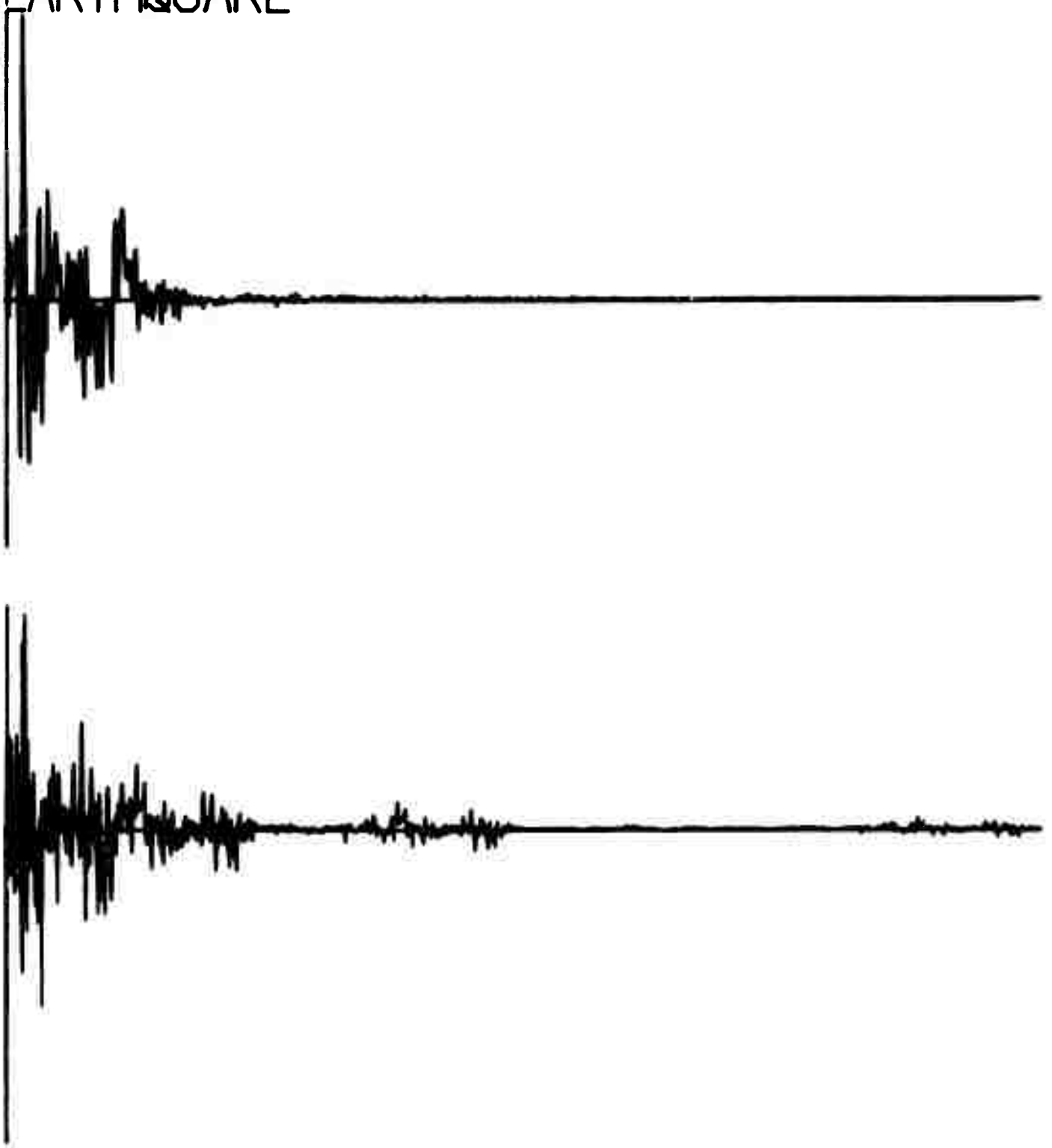
Q094

EVENT NUMBER 1020
EARTHQUAKE

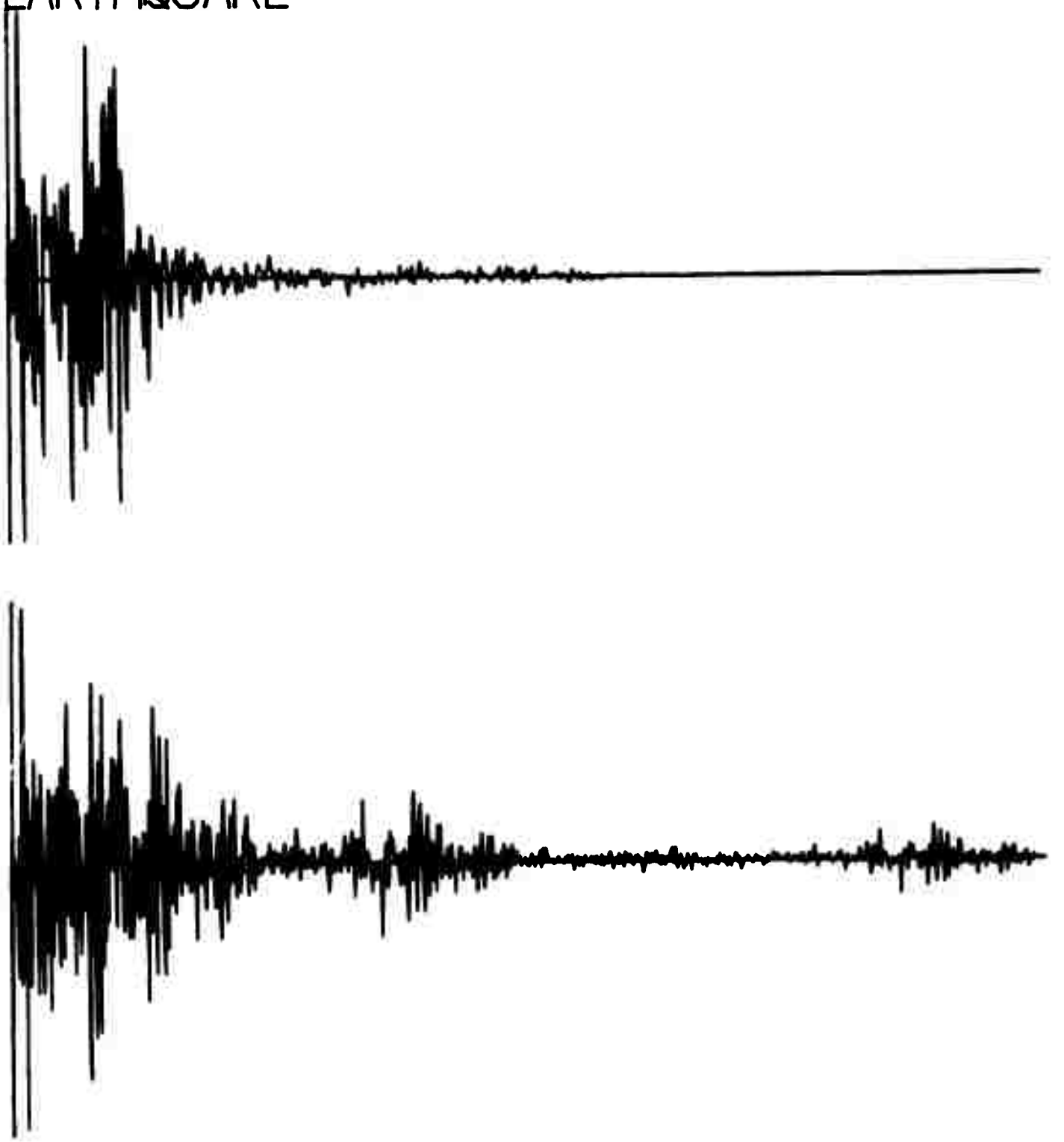


Q096

LVENT NUMBER 1029
EARTHQUAKE

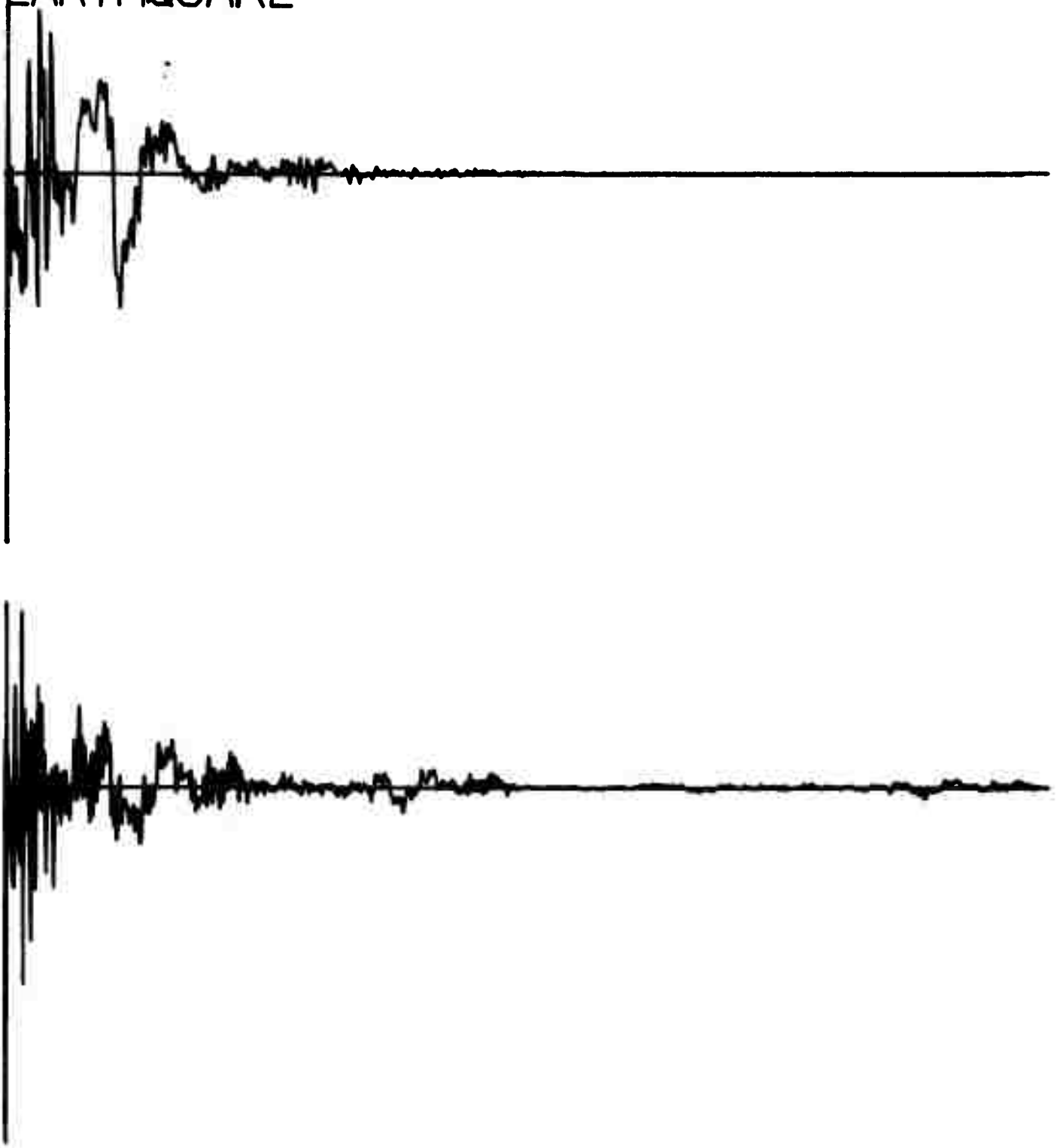


EVENT NUMBER 1030
EARTHQUAKE



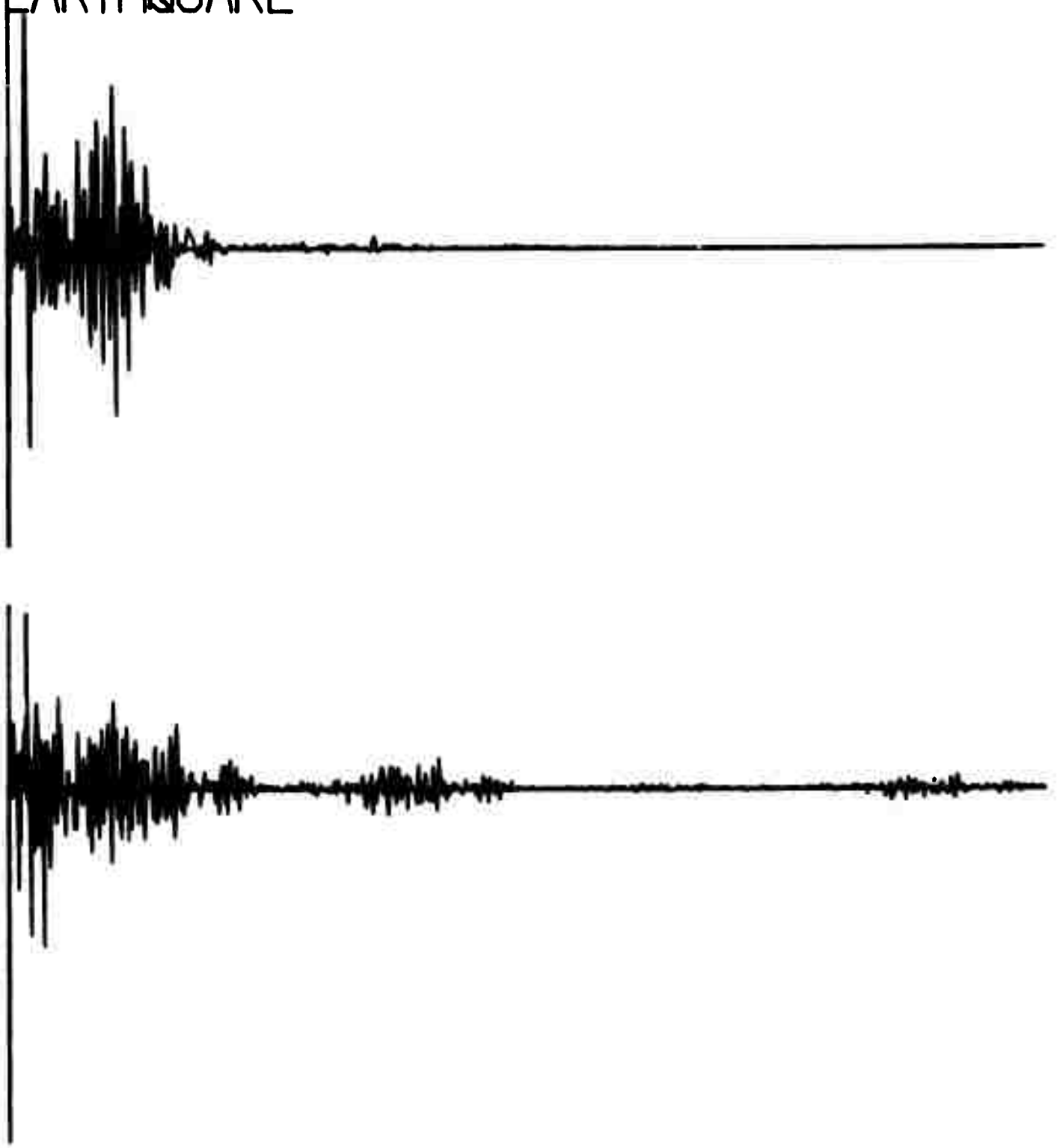
Q100

VENT NUMBER 1036
EARTHQUAKE

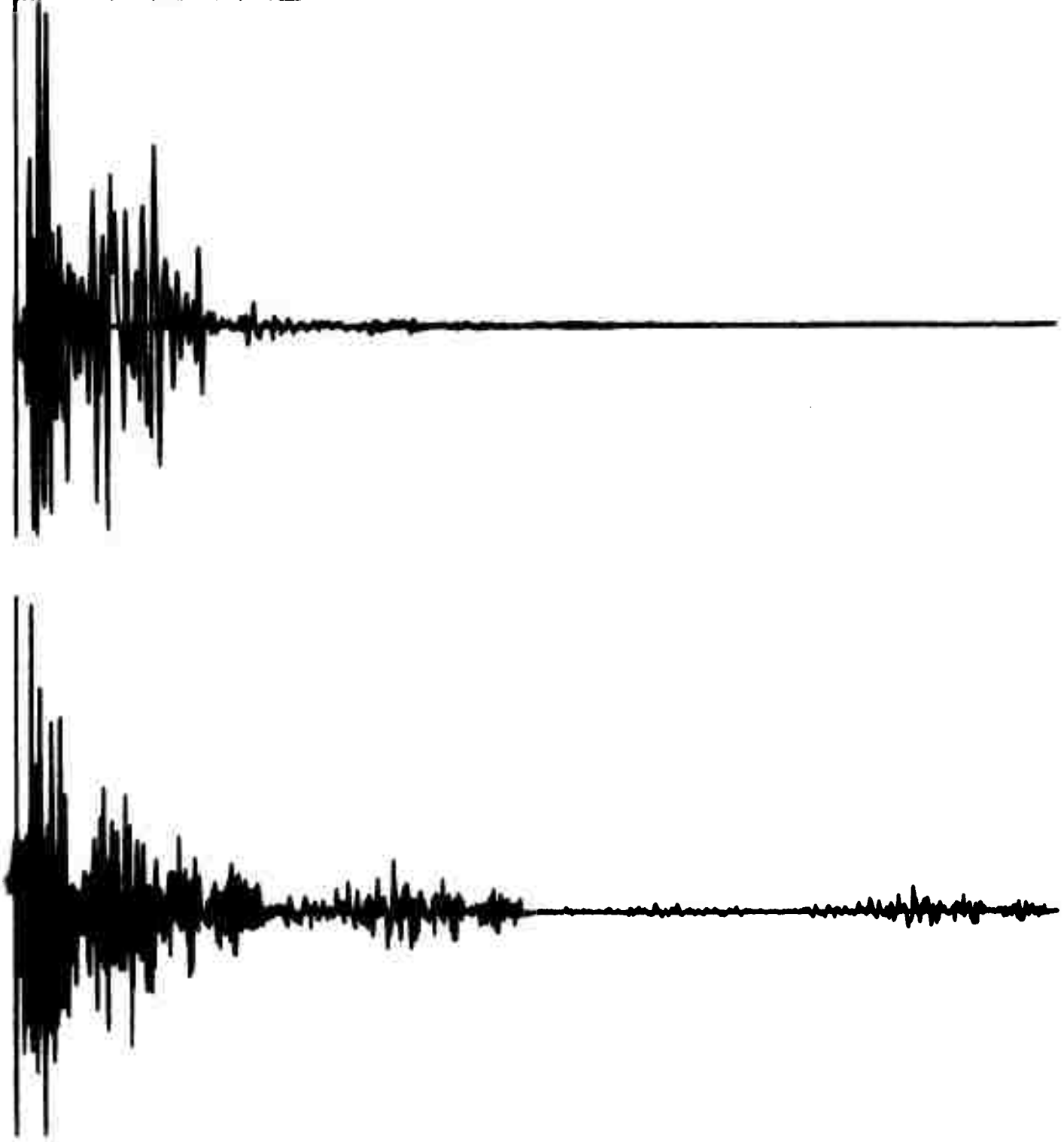


Q102

VENT NUMBER 1040
EARTHQUAKE

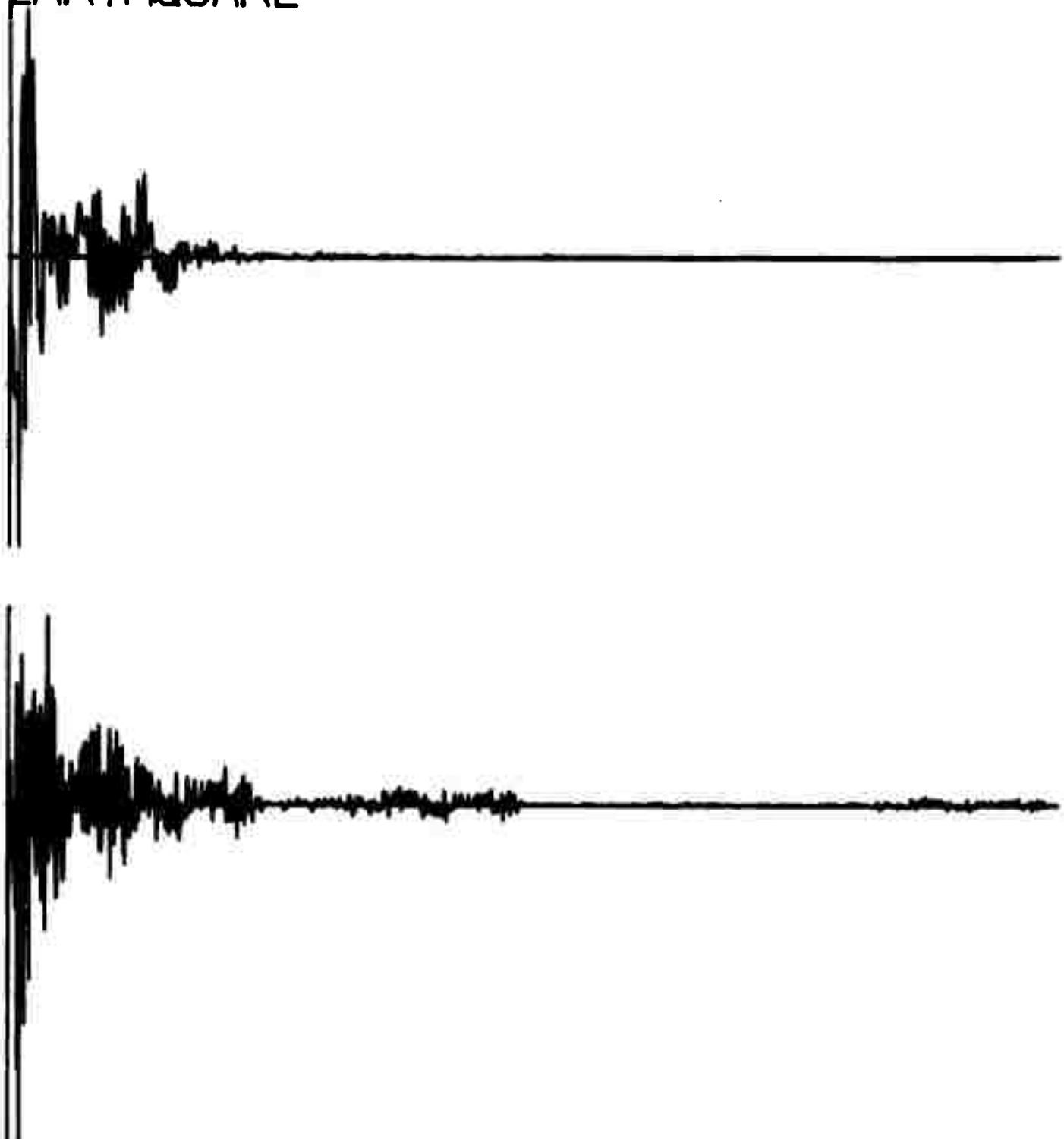


EVENT NUMBER 1059
EARTHQUAKE



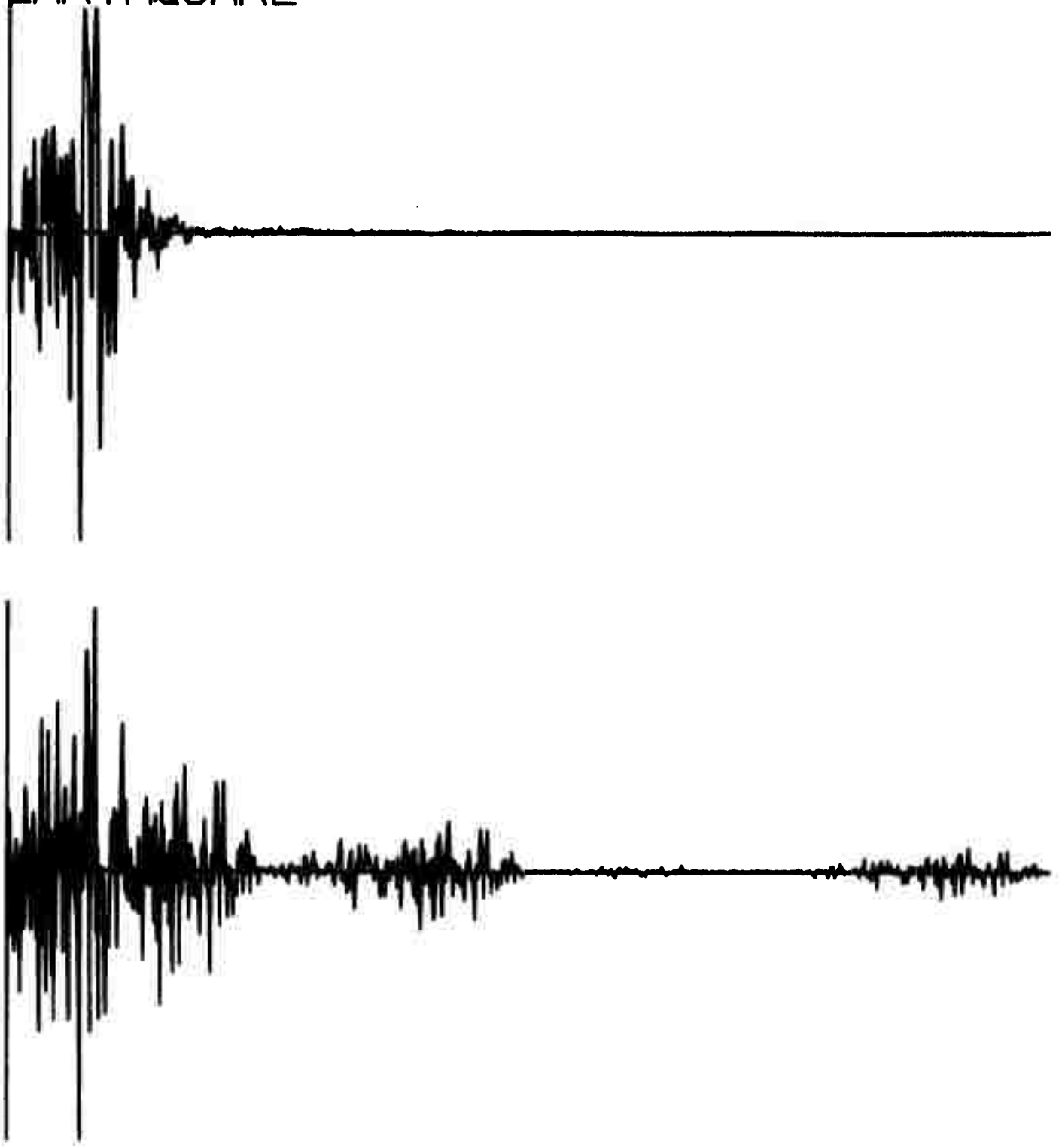
Q106

VENT NUMBER 1065
EARTHQUAKE

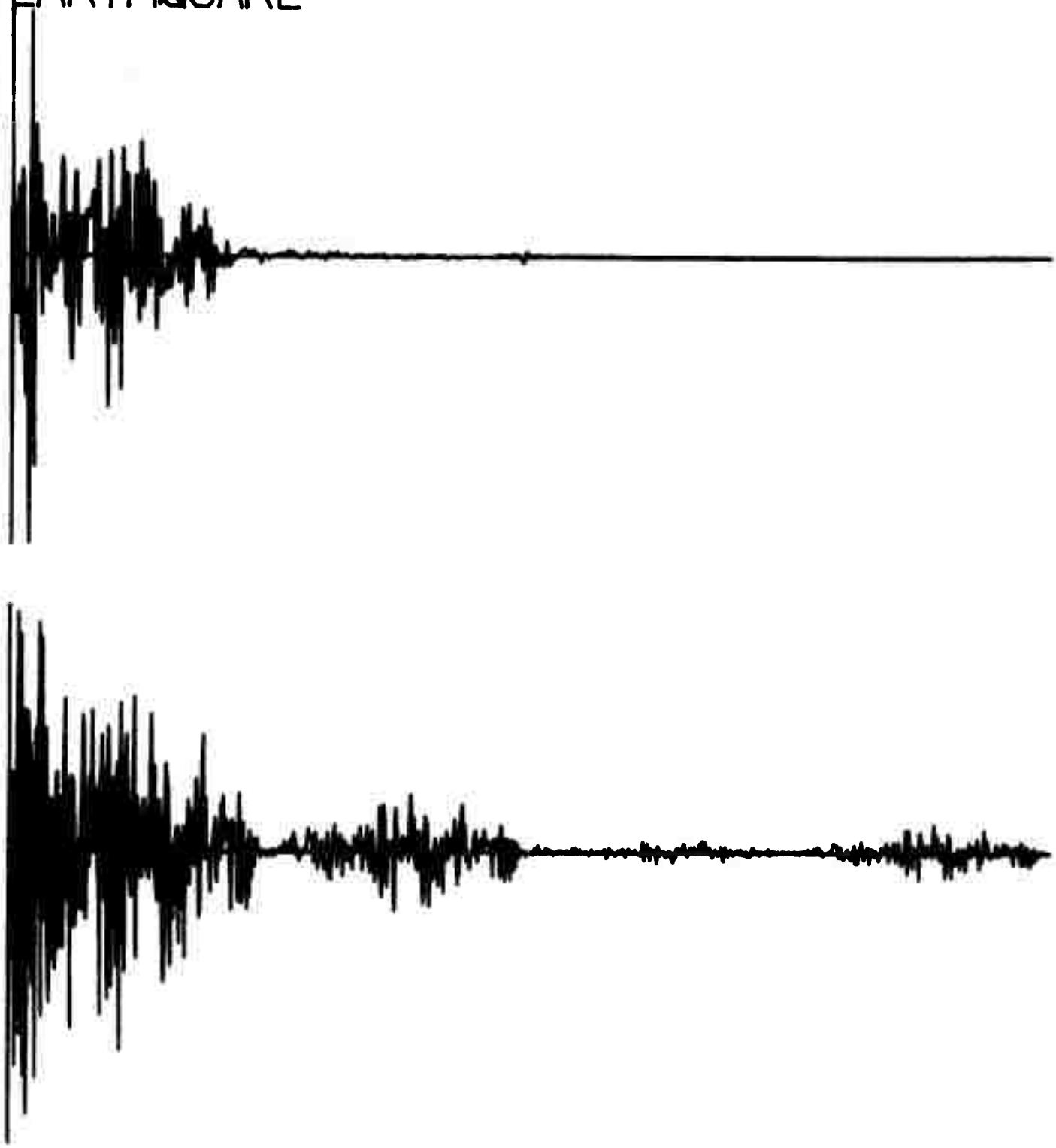


Q108

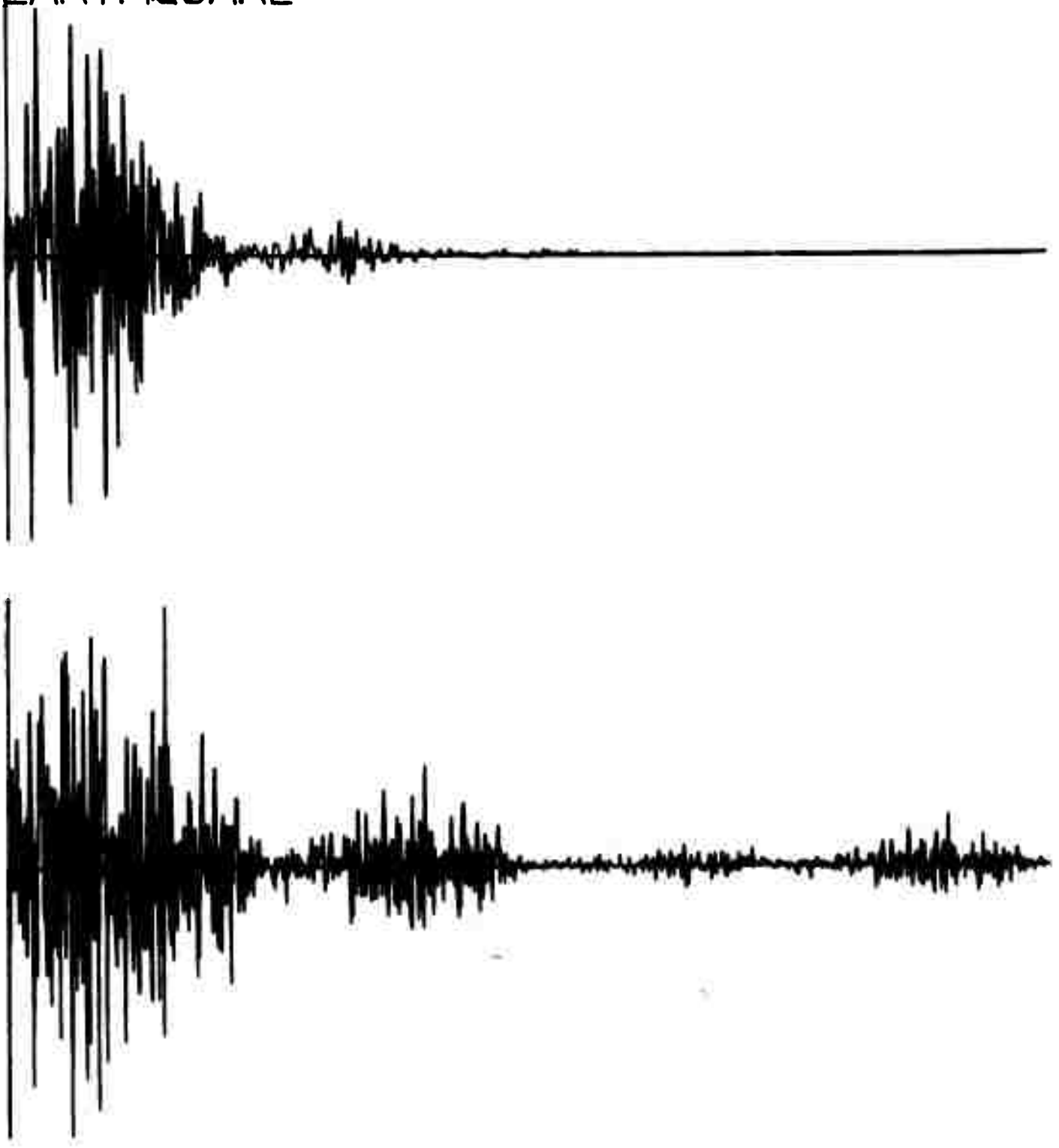
EVENT NUMBER 1070
EARTHQUAKE



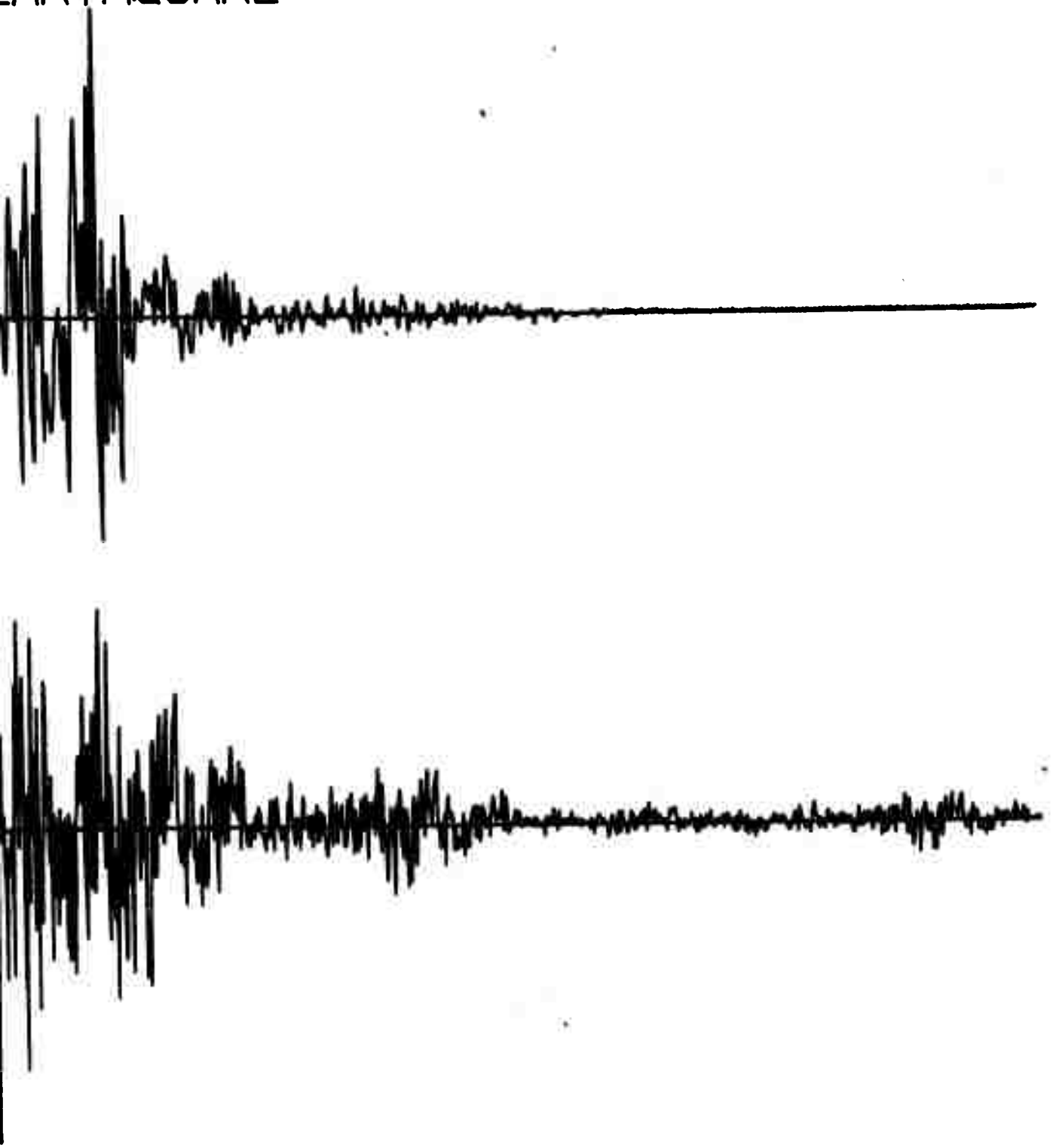
EVENT NUMBER 1066
EARTHQUAKE



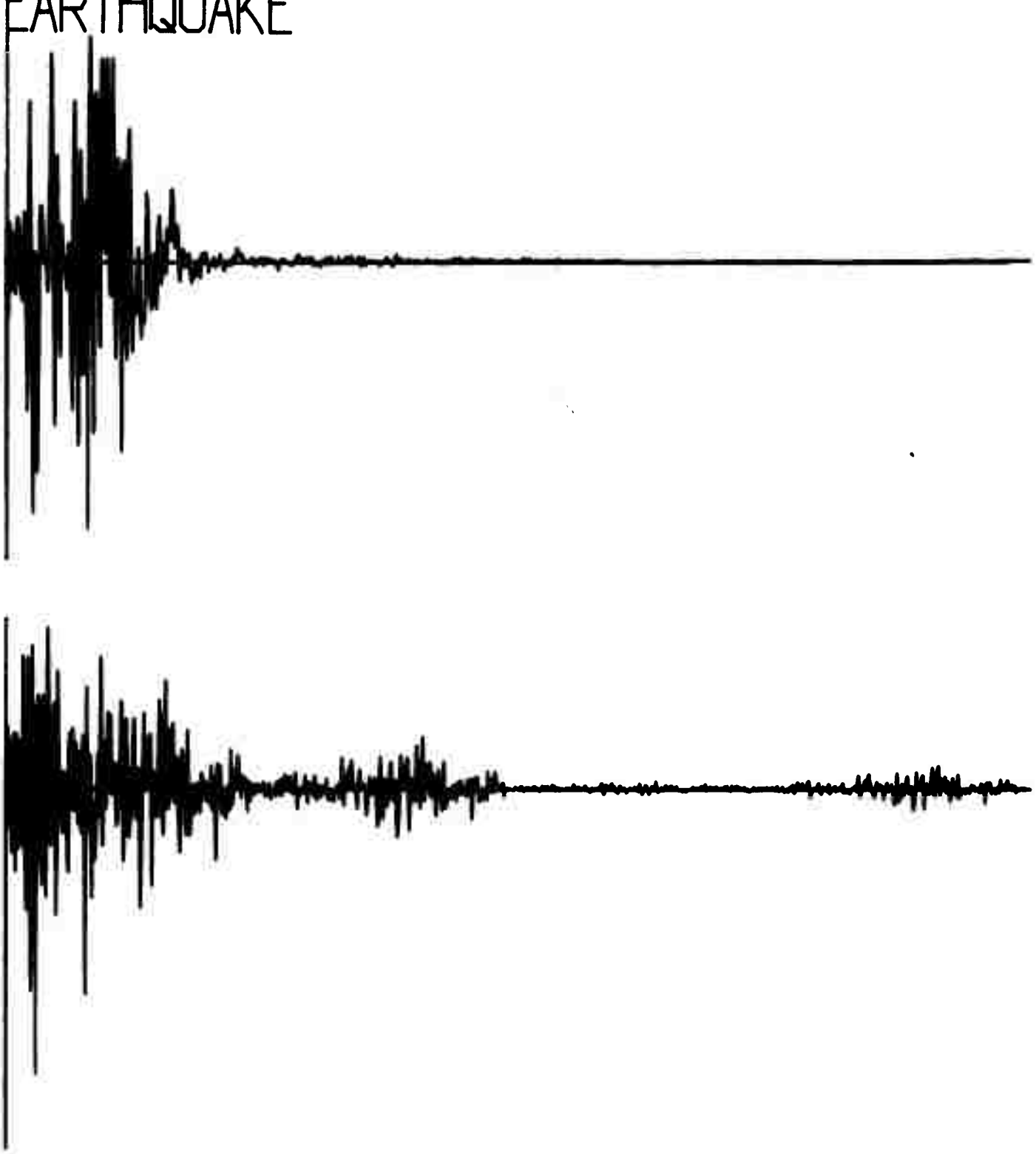
VENT NUMBER 1073
EARTHQUAKE



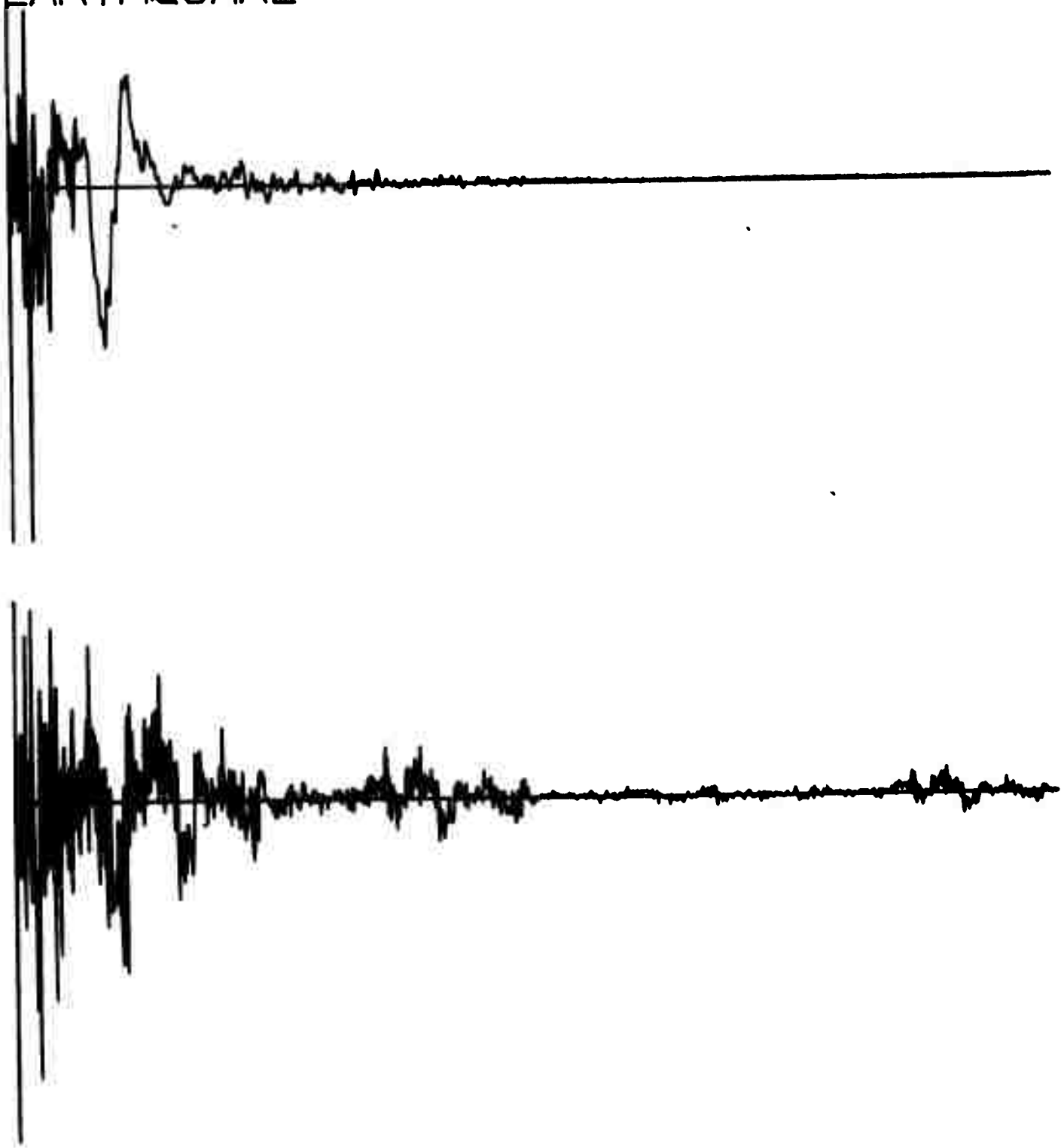
VENT NUMBER 1088
EARTHQUAKE



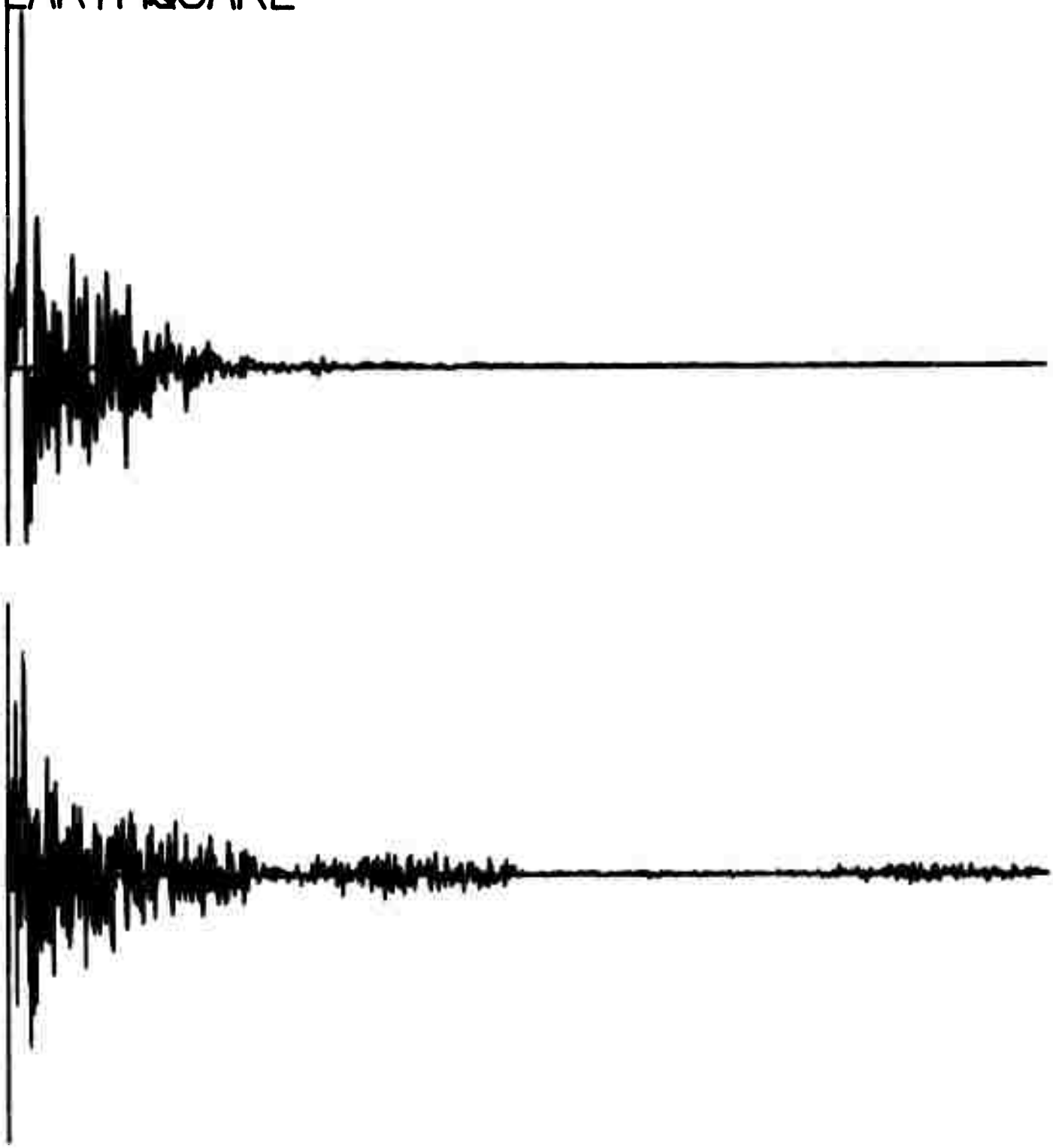
EVENT NUMBER 1084
EARTHQUAKE



EVENT NUMBER 1083
EARTHQUAKE



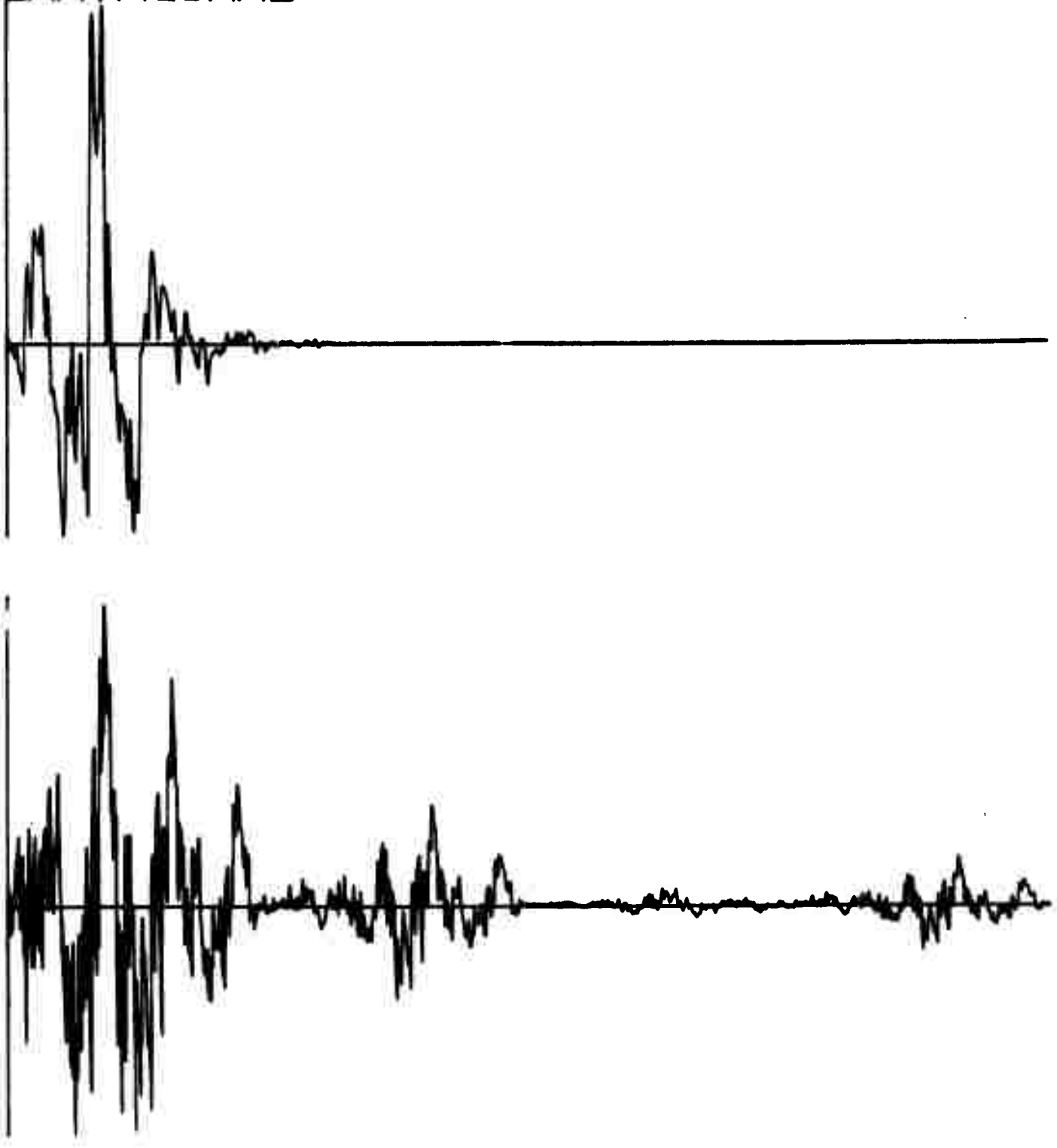
EVENT NUMBER 1089
EARTHQUAKE



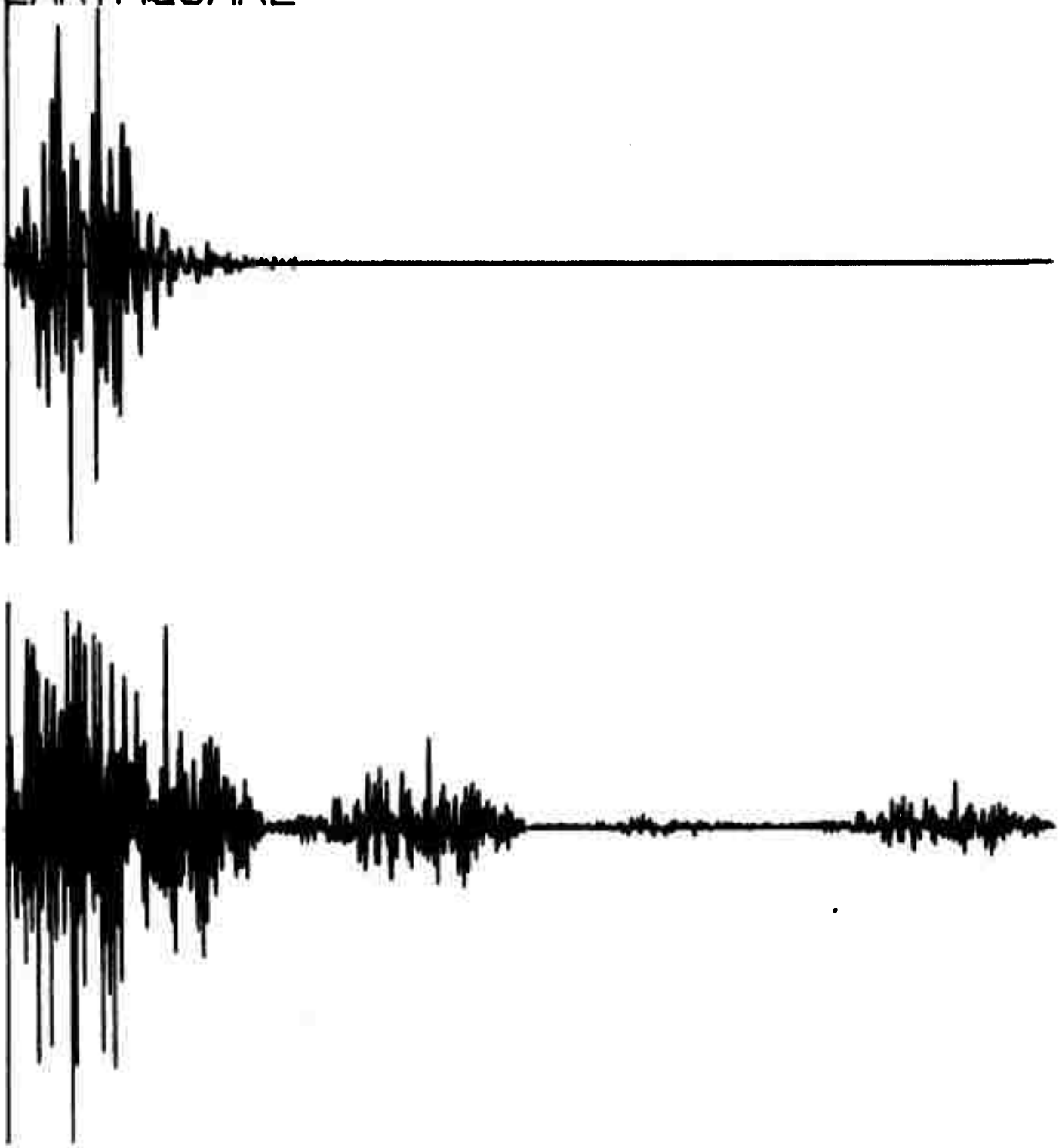
Q122

.VENT NUMBER 1111

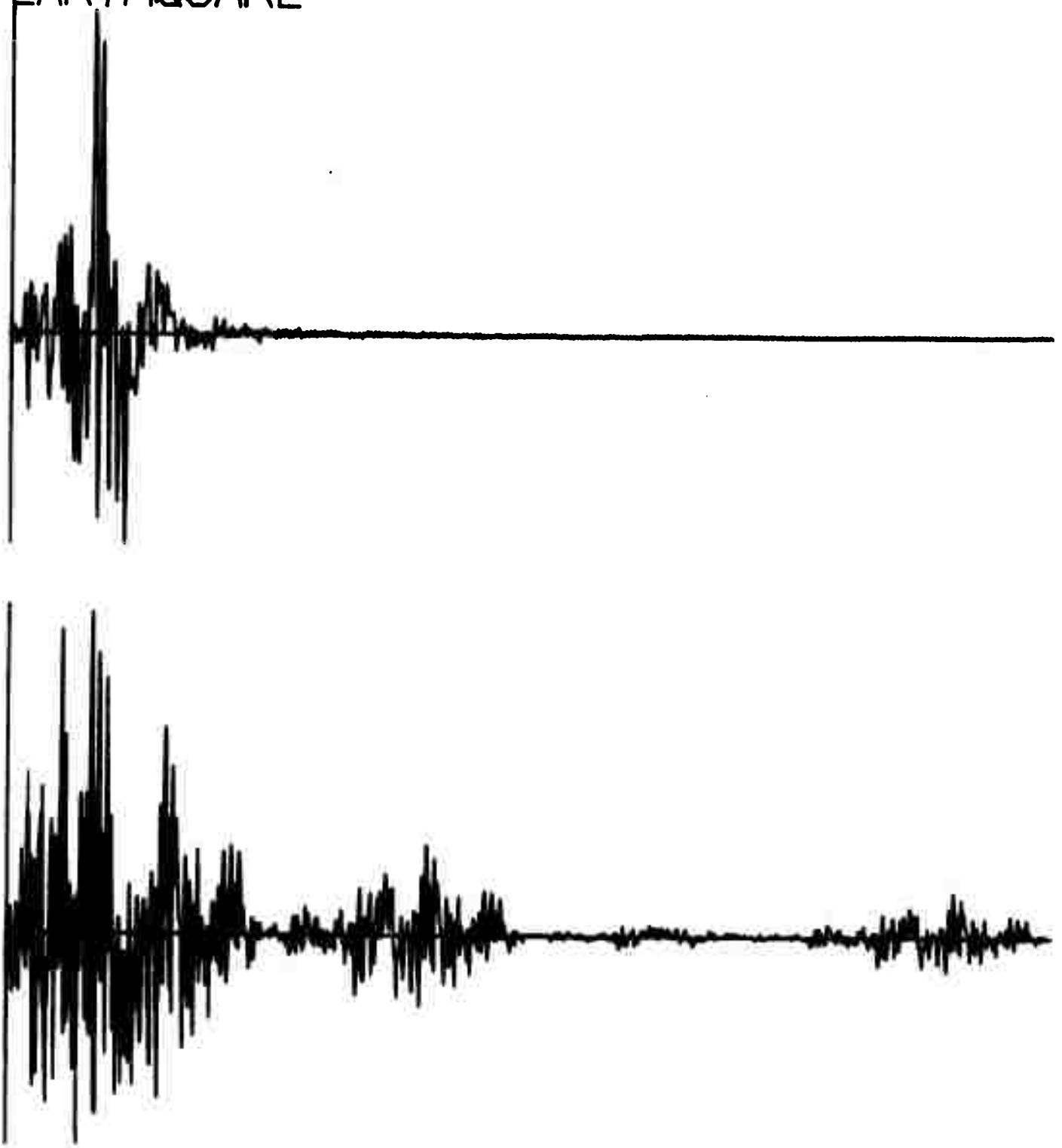
EARTHQUAKE



EVENT NUMBER 1113
EARTHQUAKE

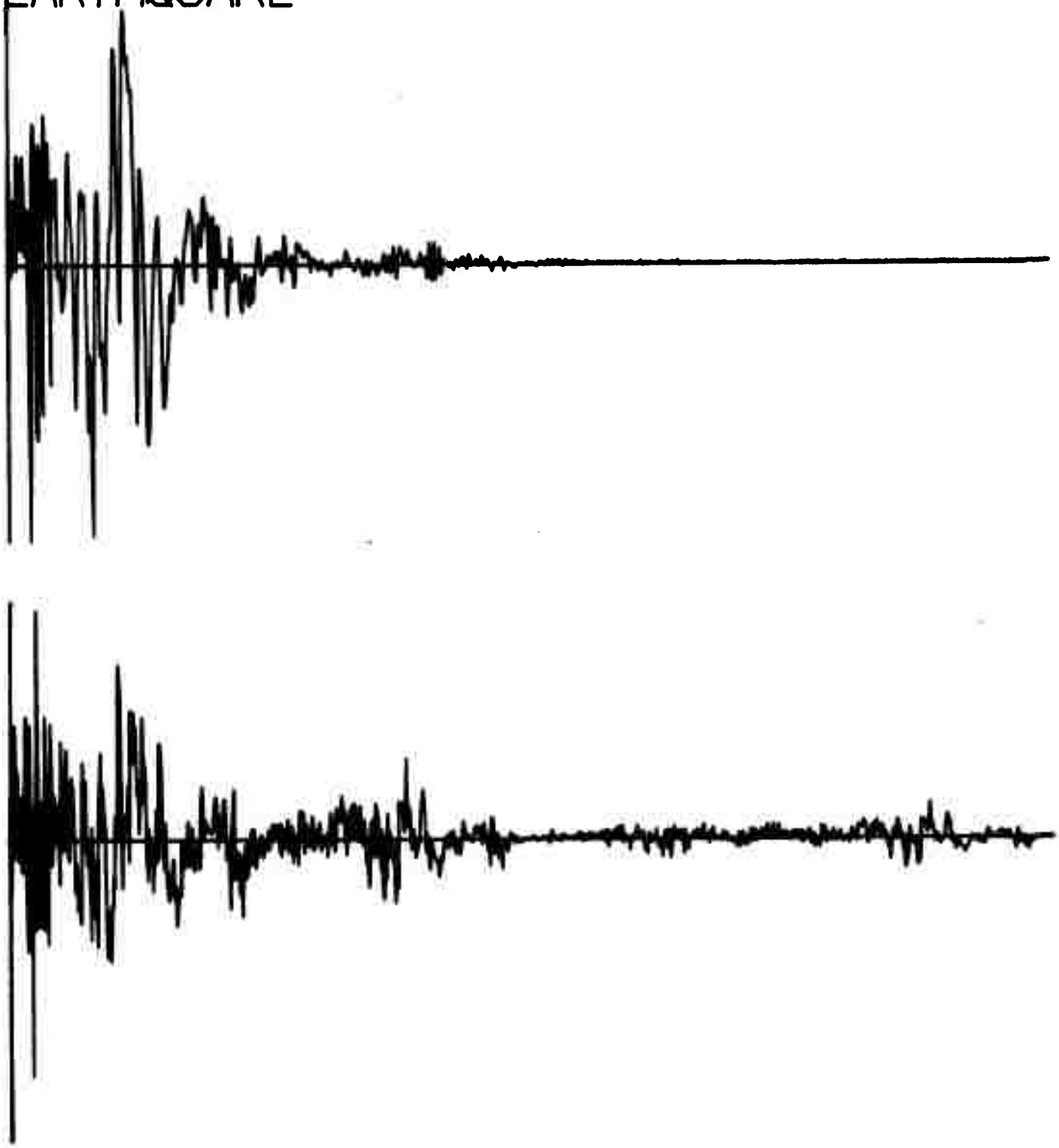


EVENT NUMBER 1201
EARTHQUAKE

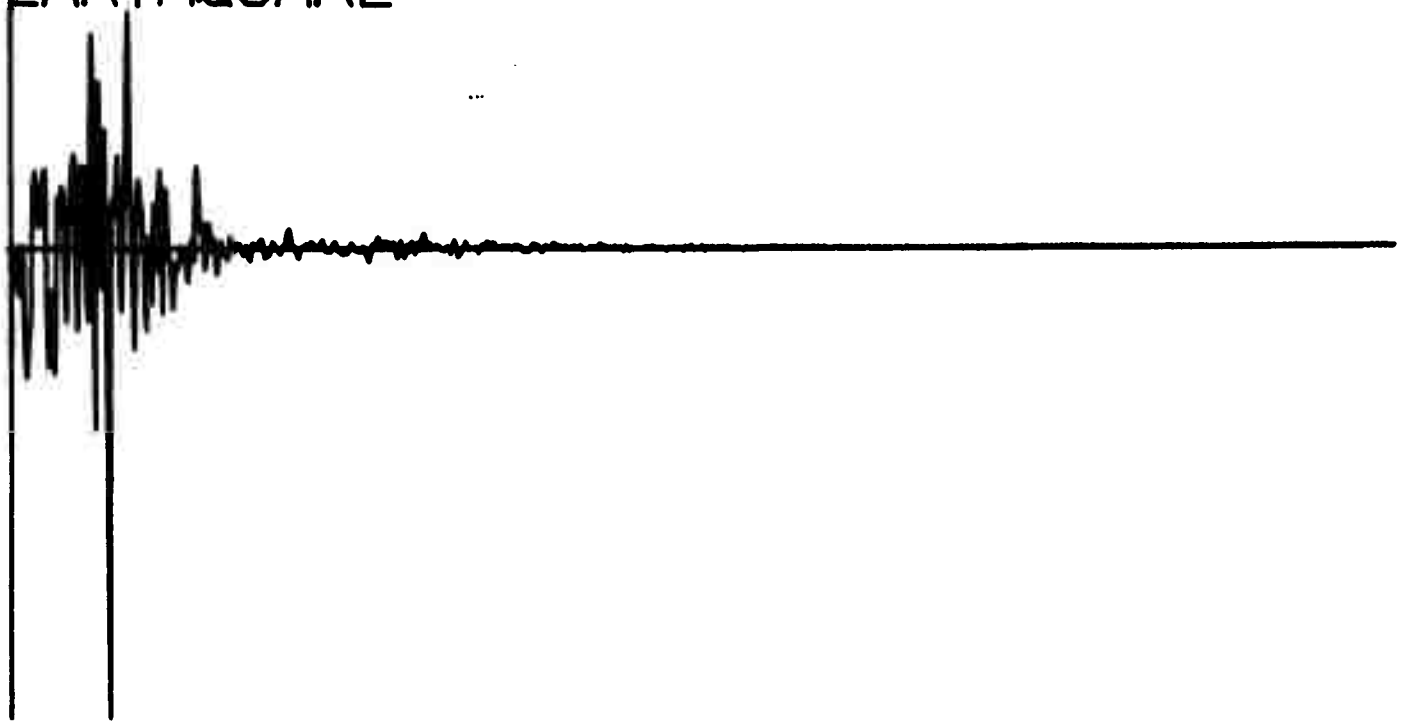


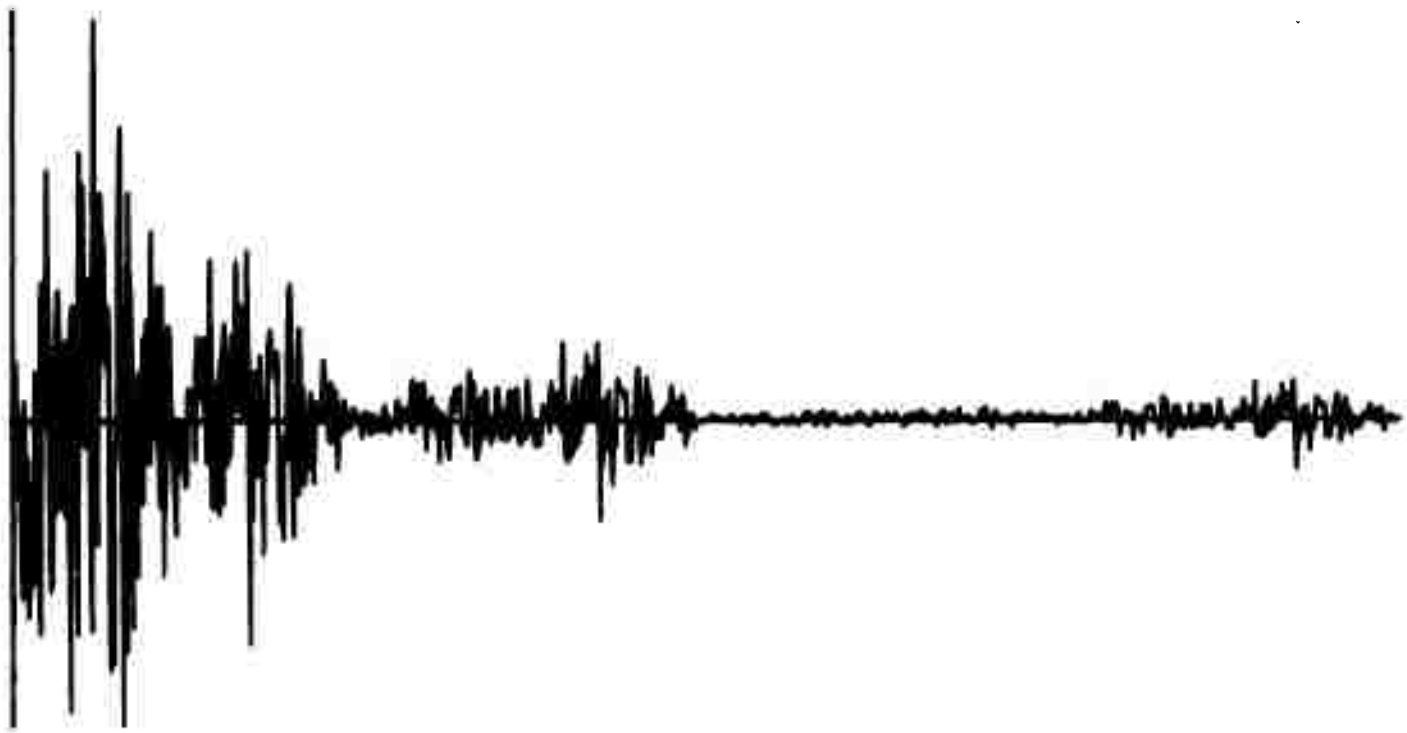
Q128

L'VENT NUMBER 1104
EARTHQUAKE

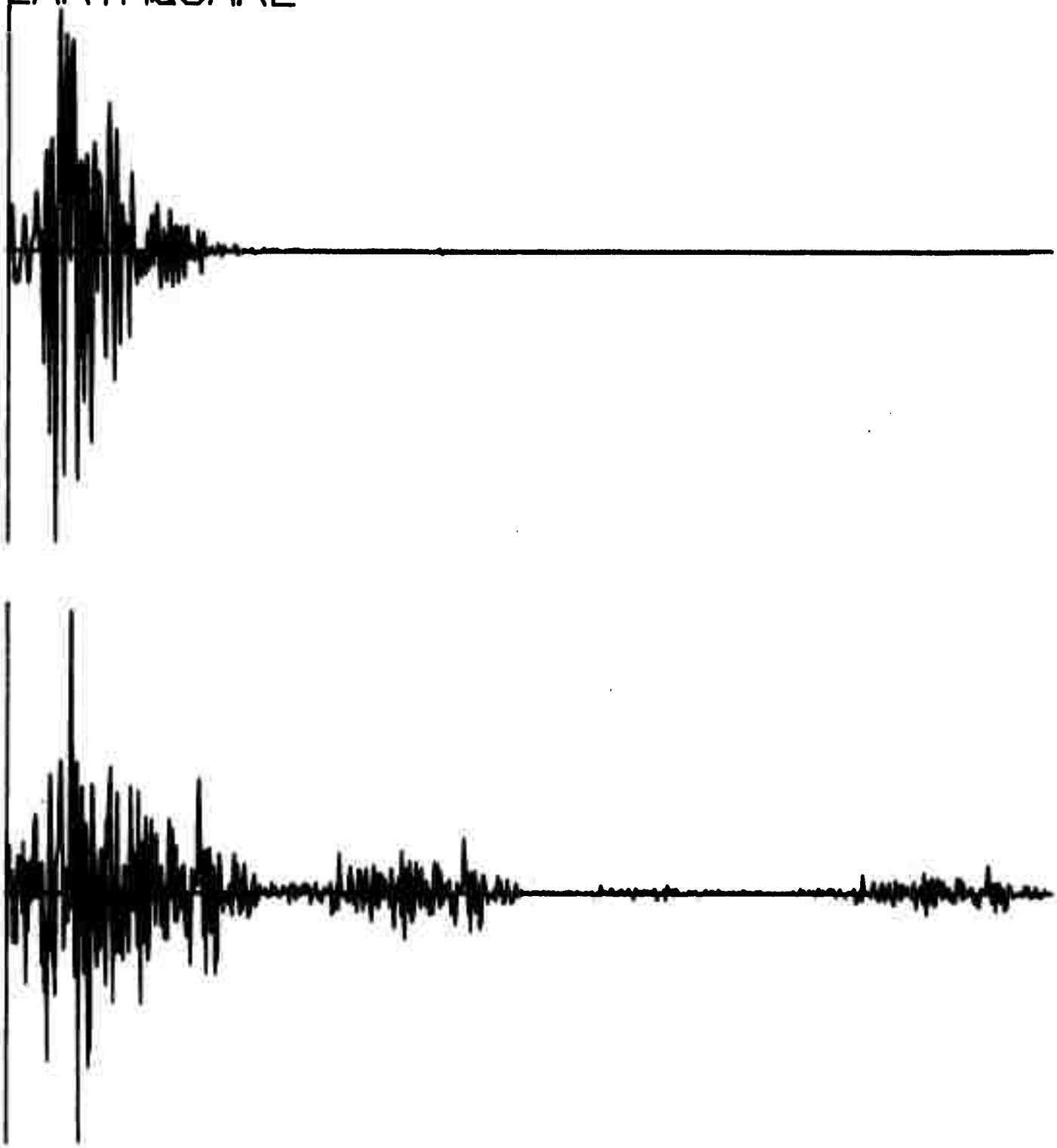


EVENT NUMBER 1068
EARTHQUAKE



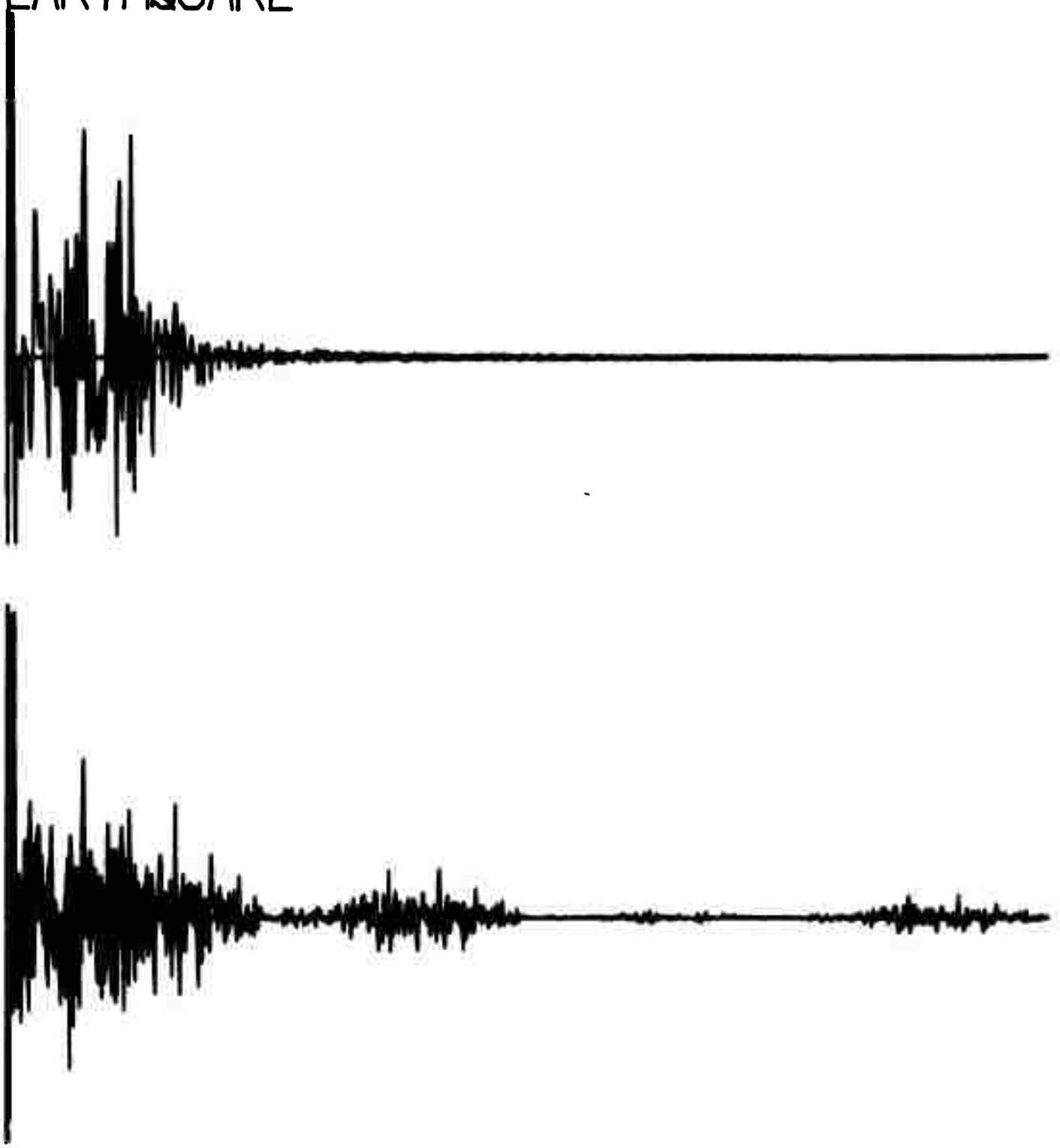


EVENT NUMBER 1114
EARTHQUAKE



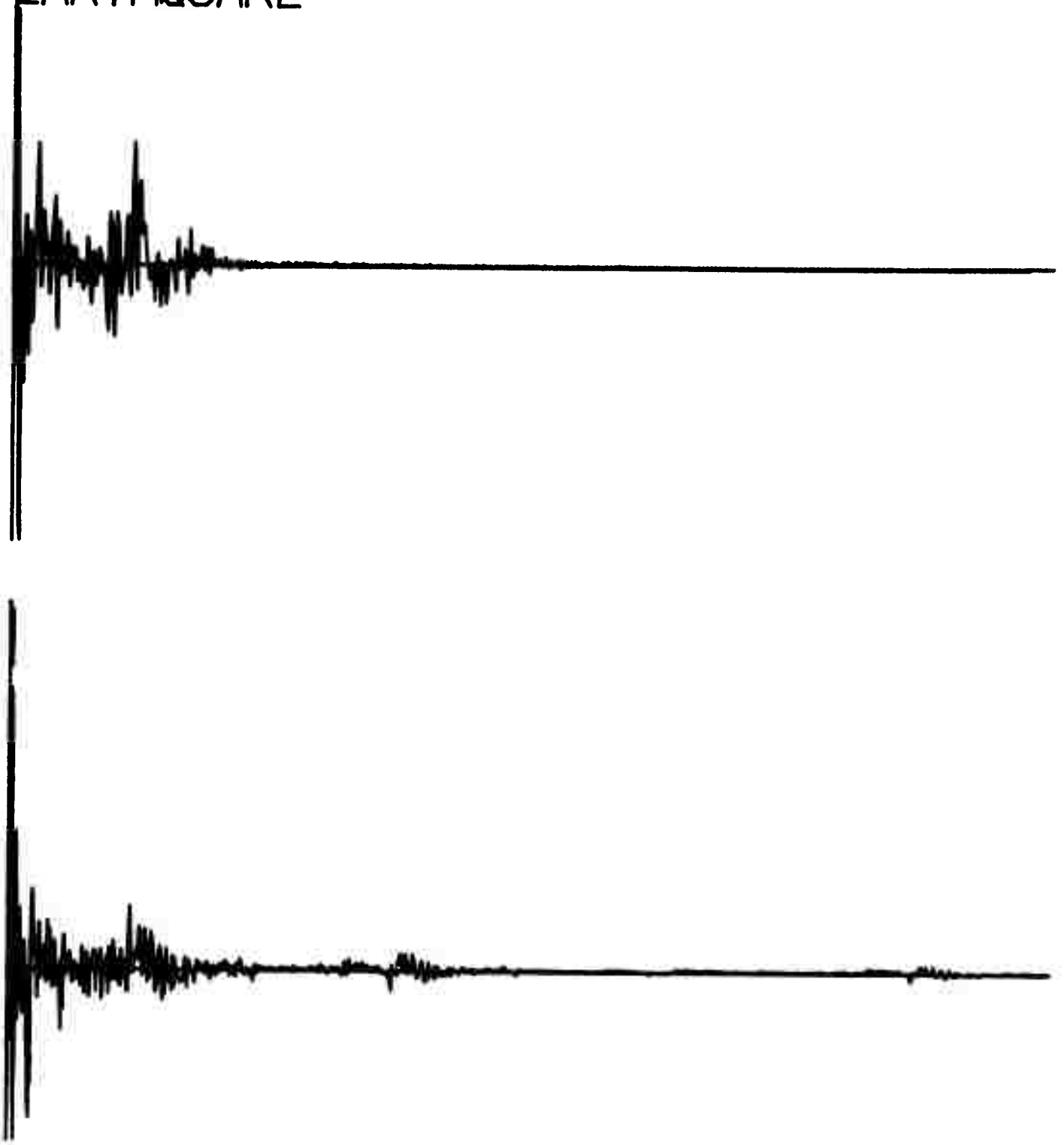
Q134

EVENT NUMBER 1115
EARTHQUAKE

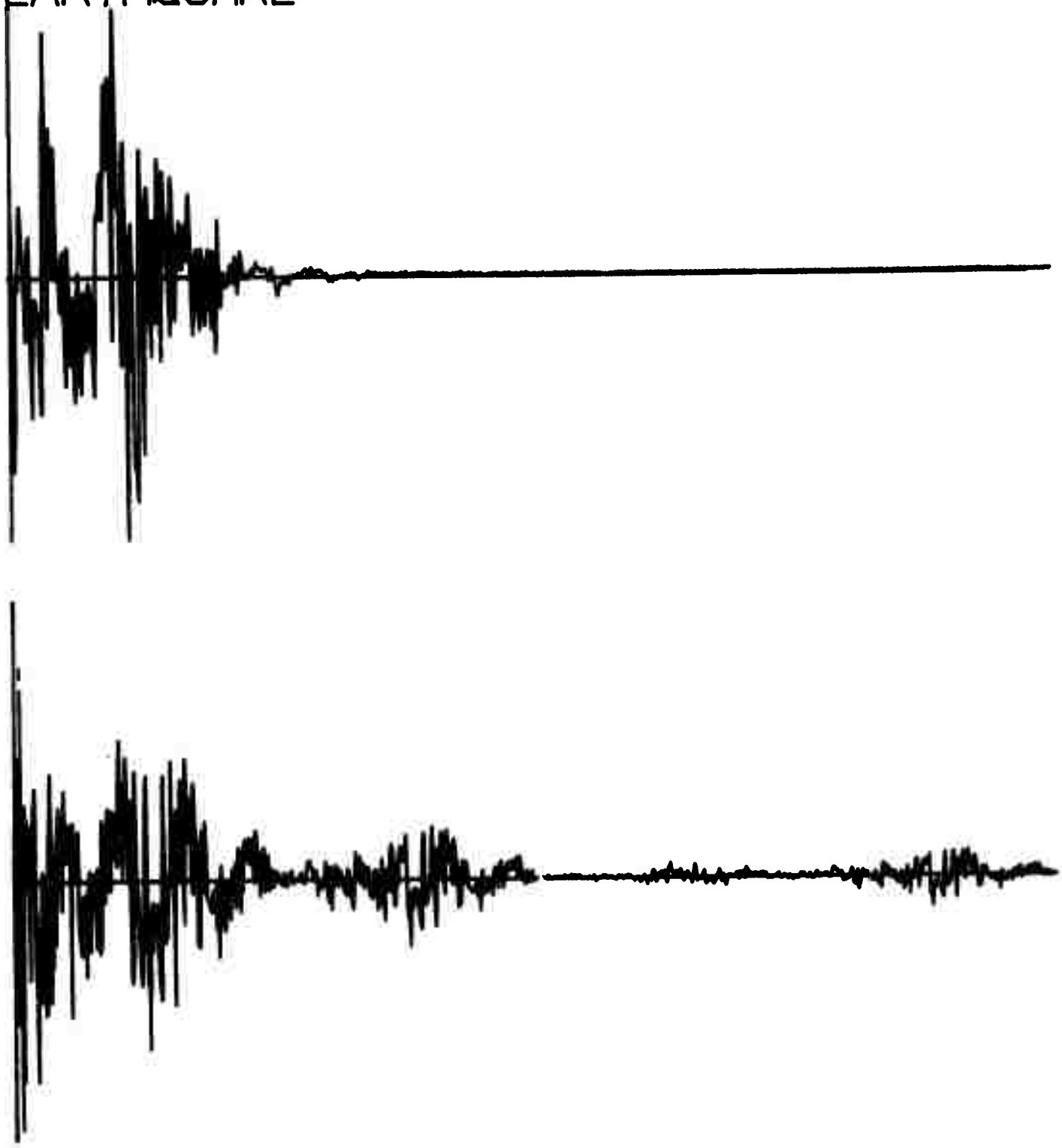


Q136

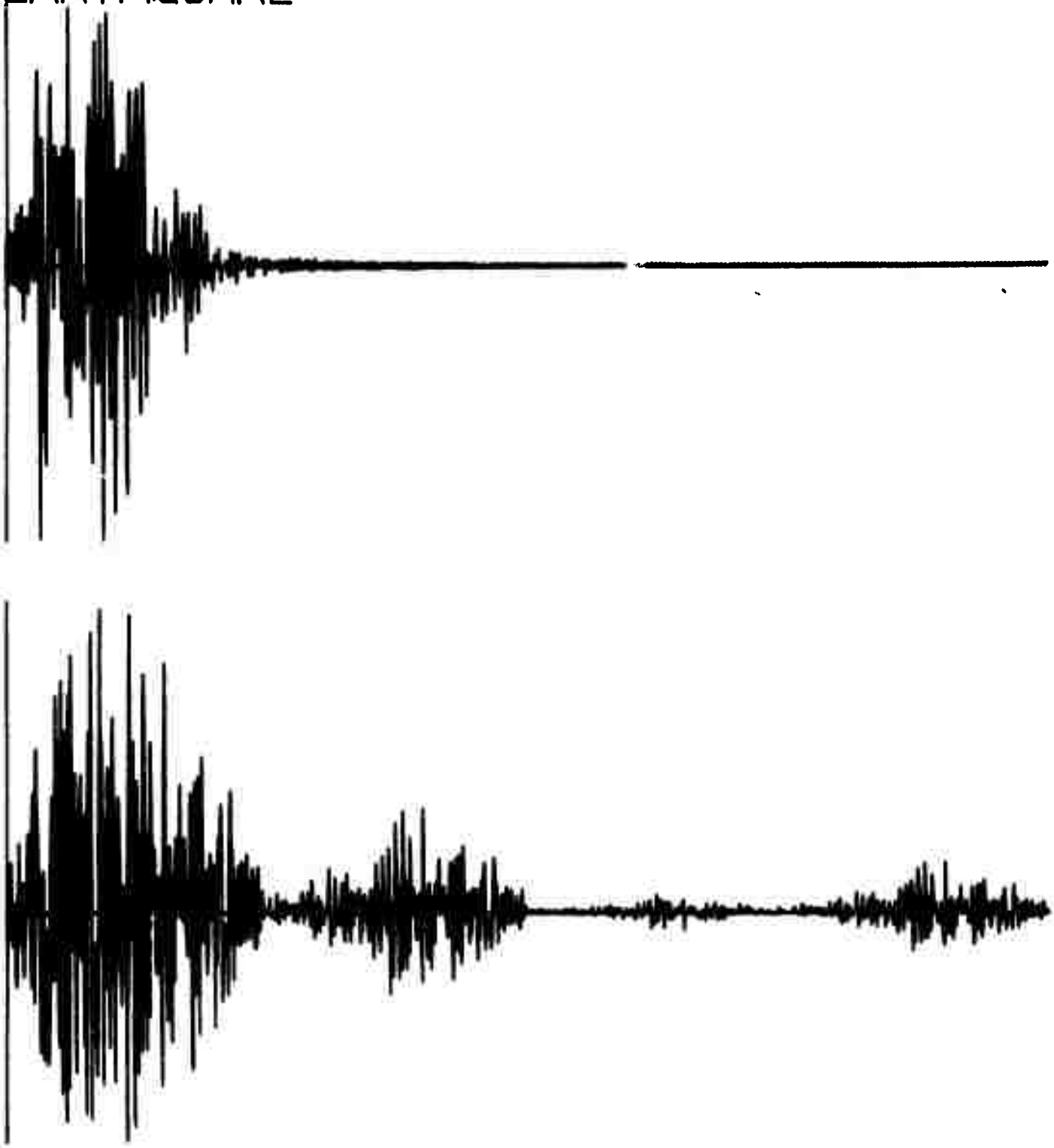
EVENT NUMBER 1116
EARTHQUAKE



EVENT NUMBER 1117
EARTHQUAKE

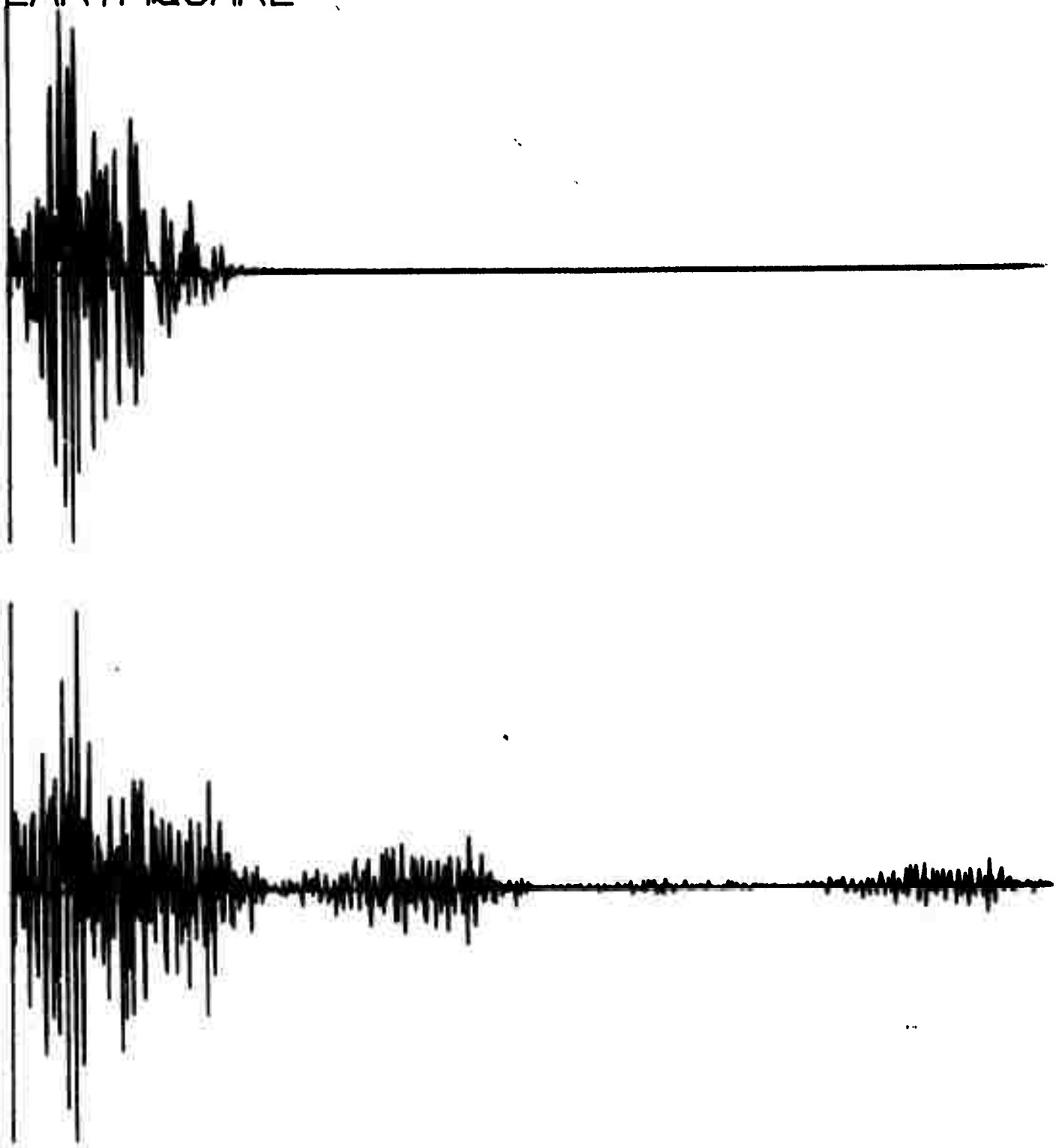


_VENT NUMBER 1118
EARTHQUAKE



Q142

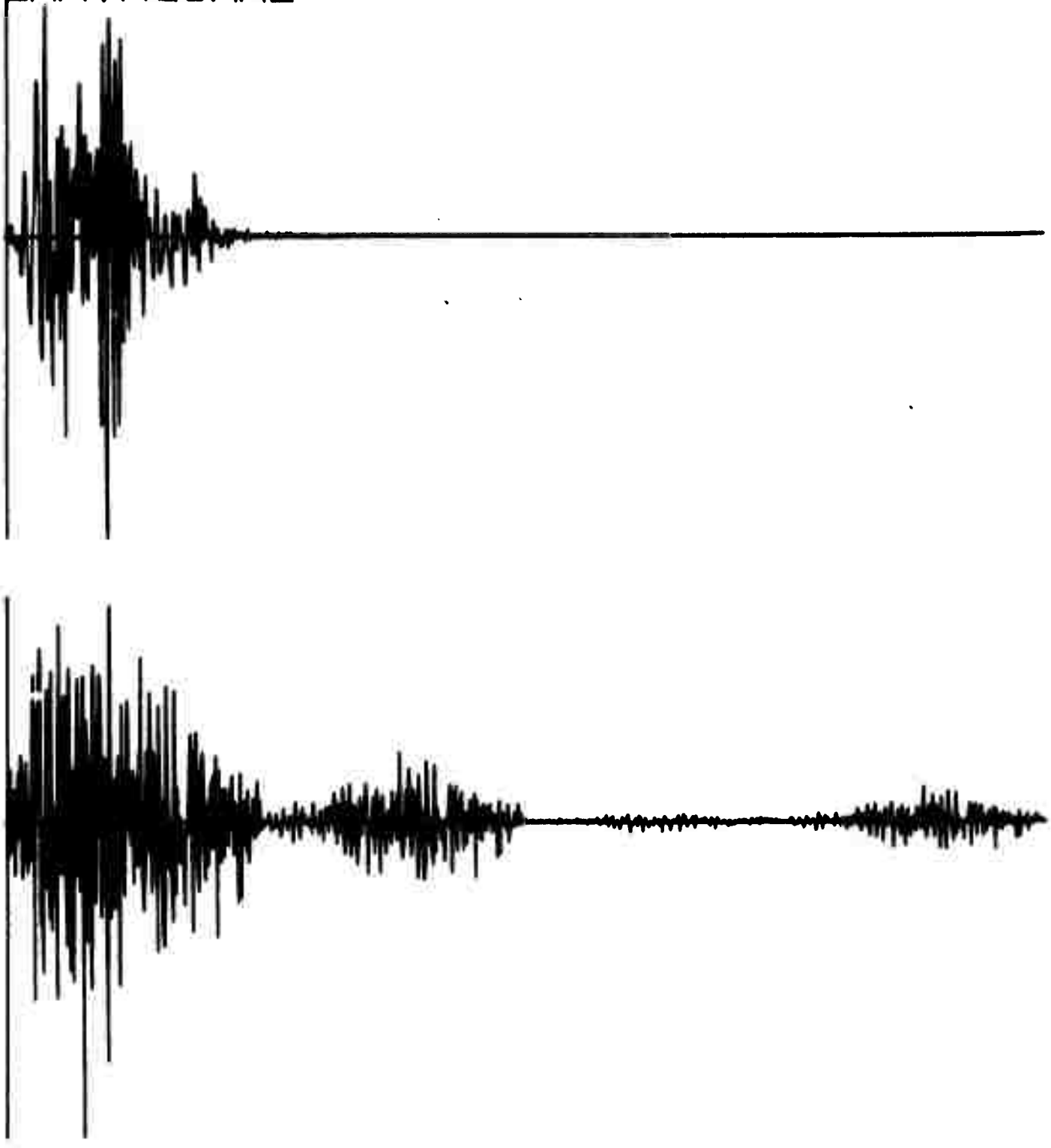
_VENT NUMBER 1119
EARTHQUAKE



EVENT NUMBER 1142

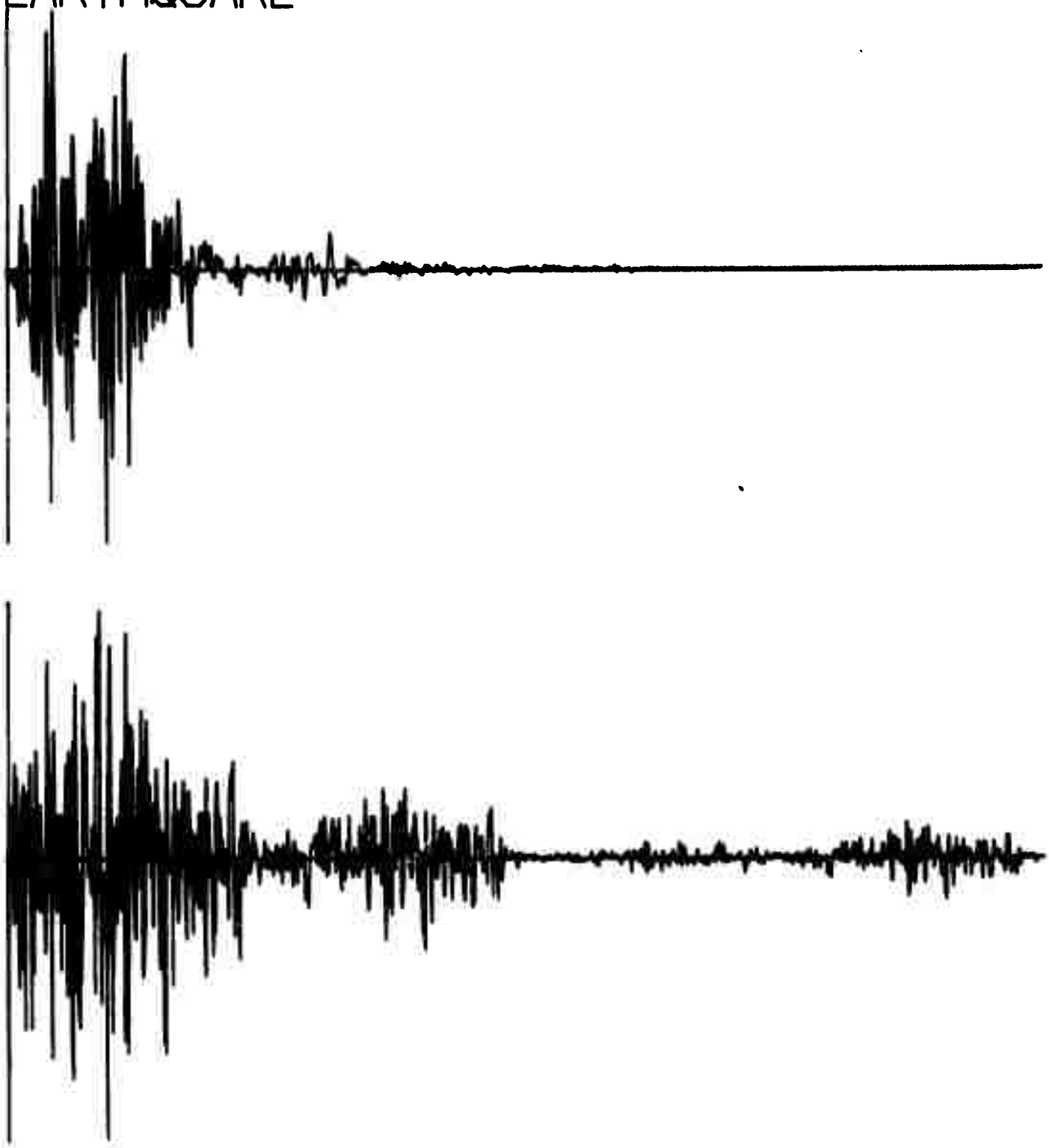
Q144

EARTHQUAKE

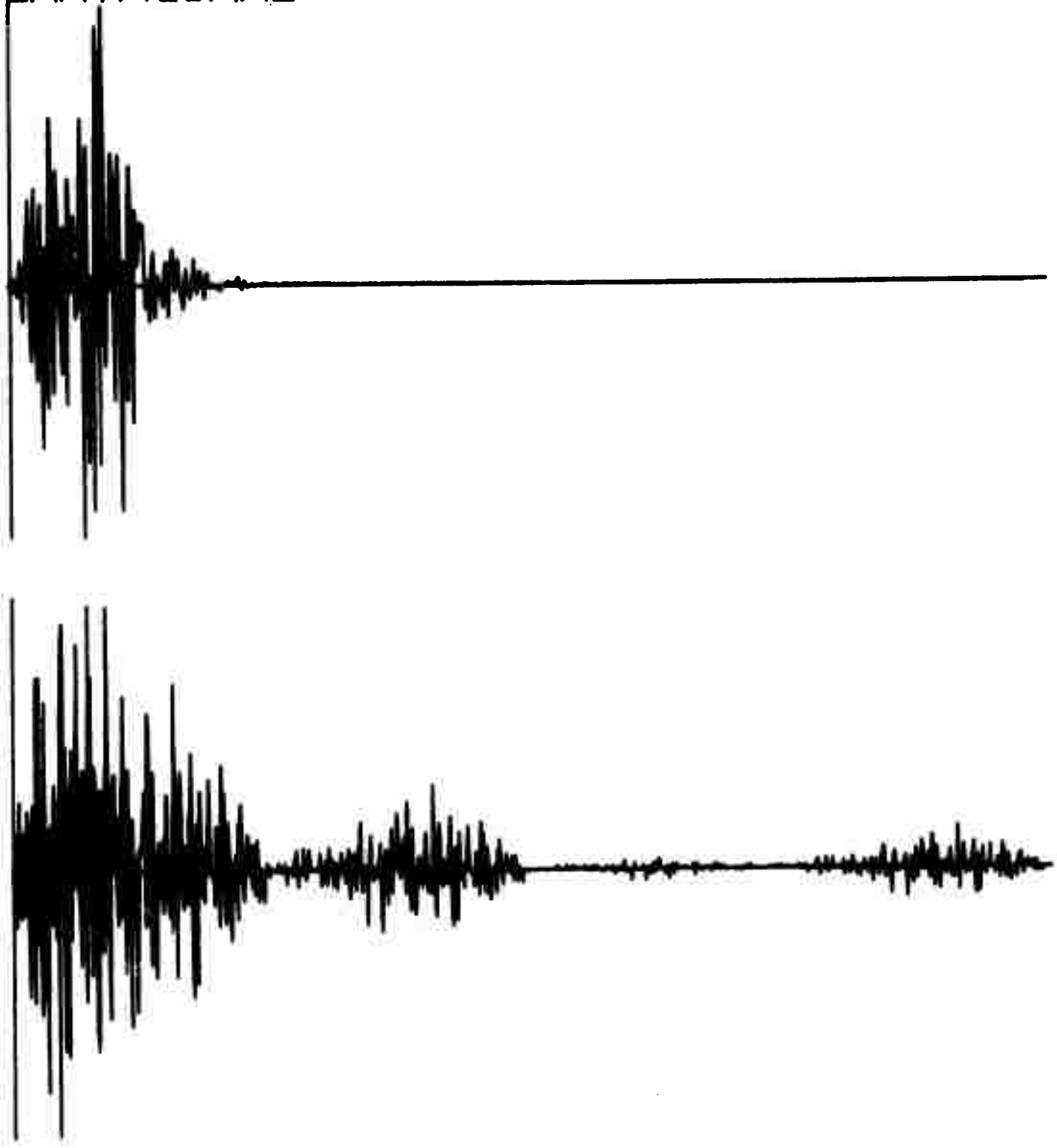


Q146

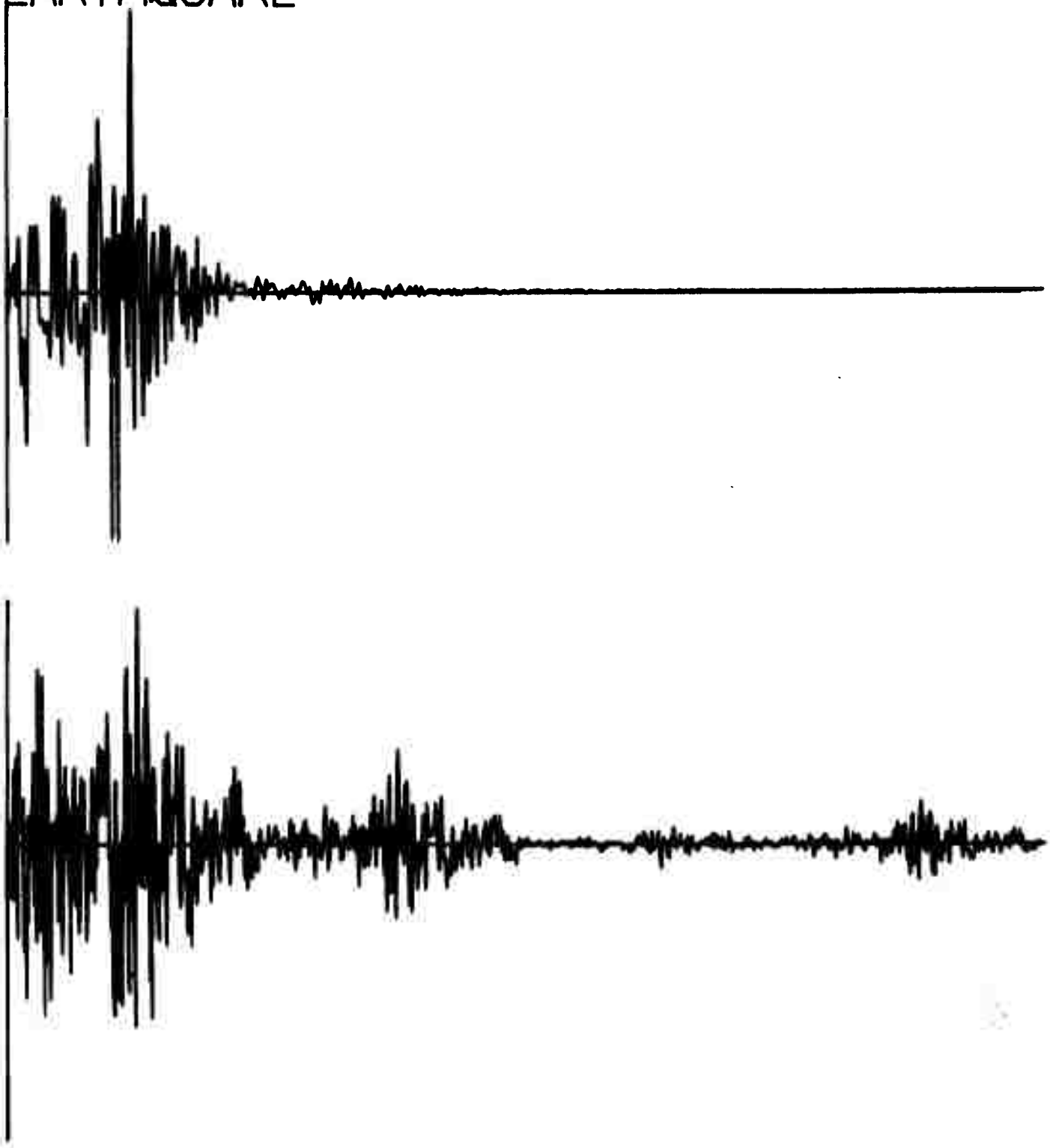
EVENT NUMBER 1132
EARTHQUAKE



EVENT NUMBER 1131
EARTHQUAKE

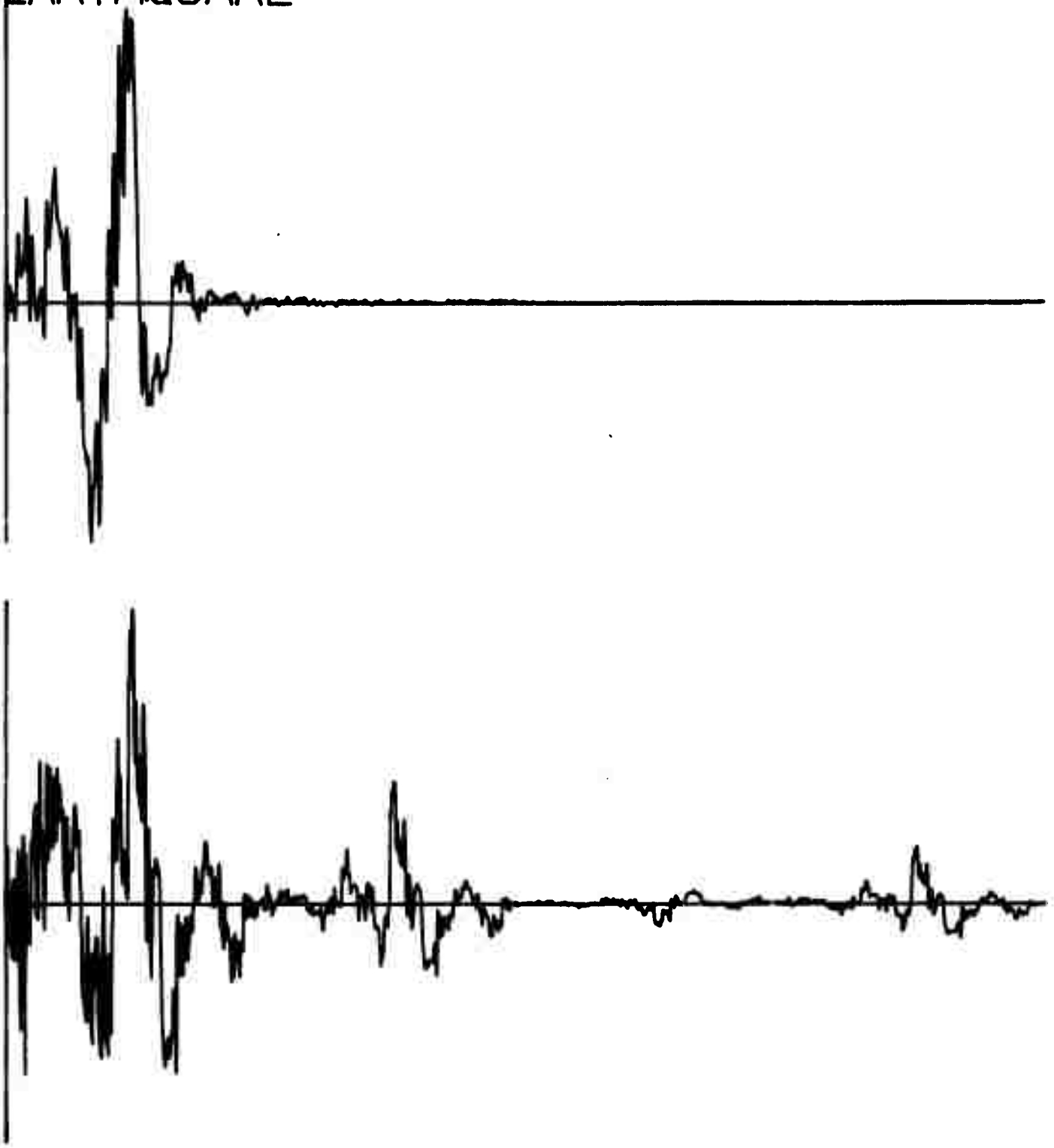


EVENT NUMBER 1130
EARTHQUAKE

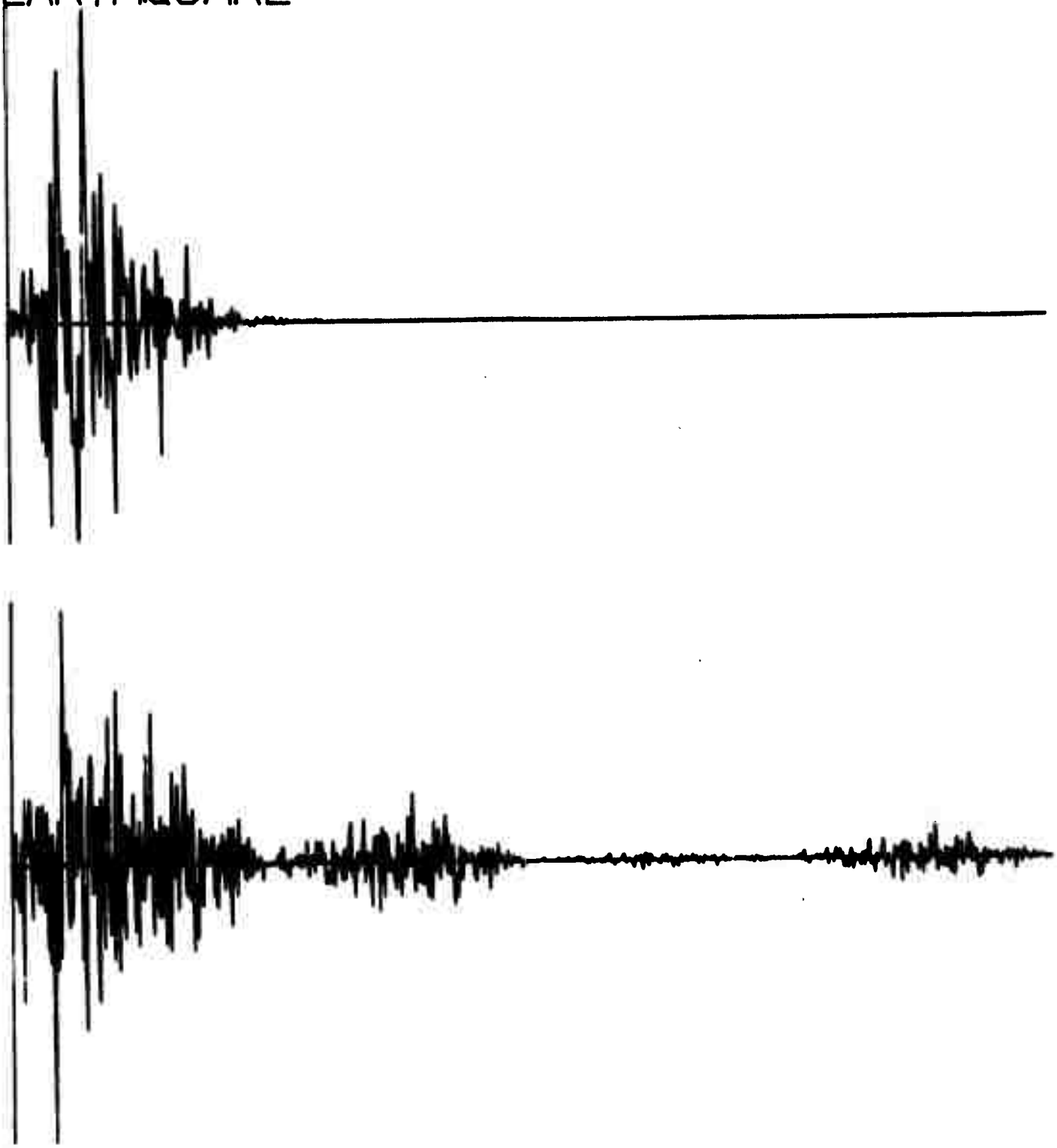


Q152

EVENT NUMBER 1159
EARTHQUAKE

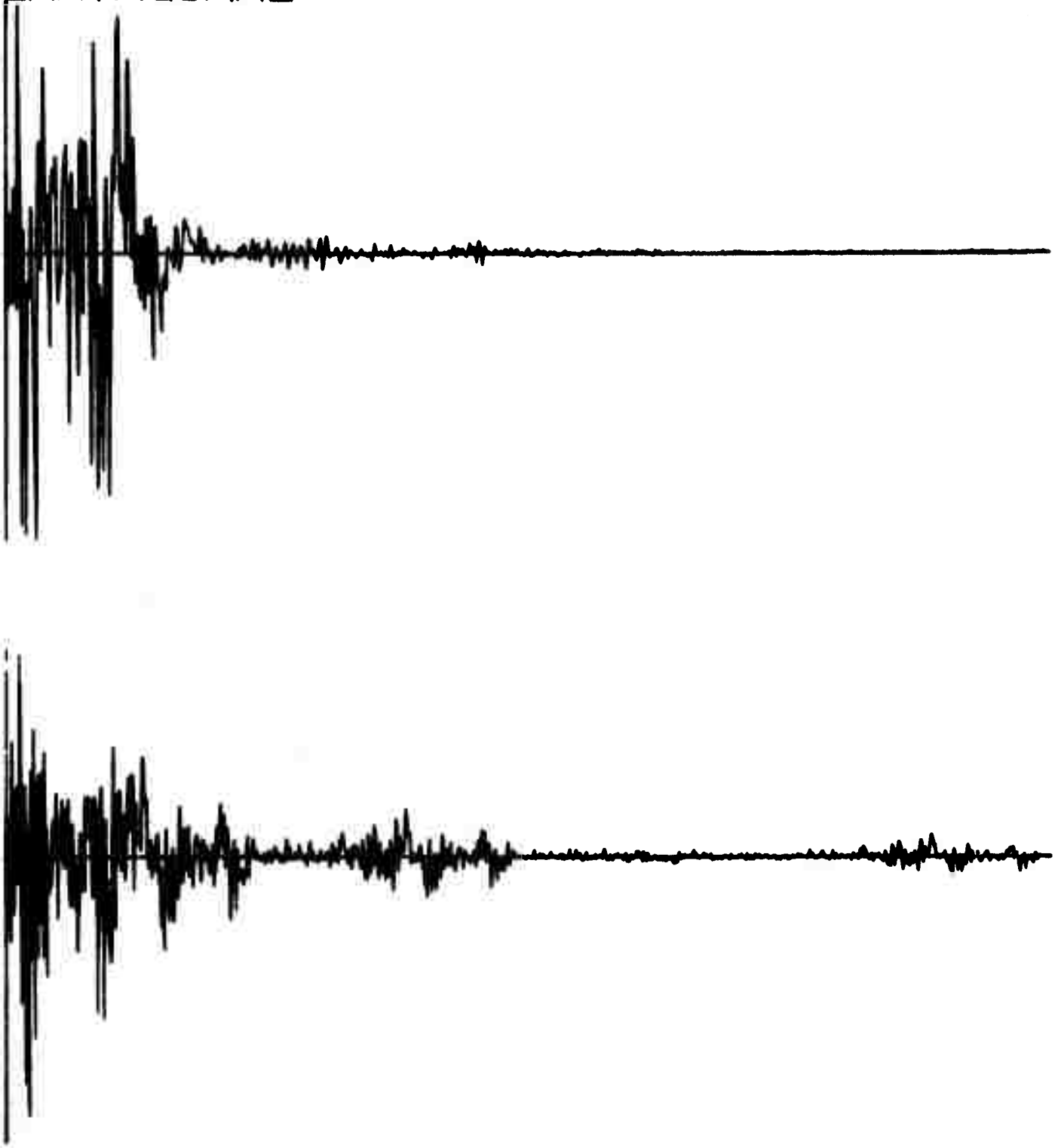


EVENT NUMBER 1141
EARTHQUAKE



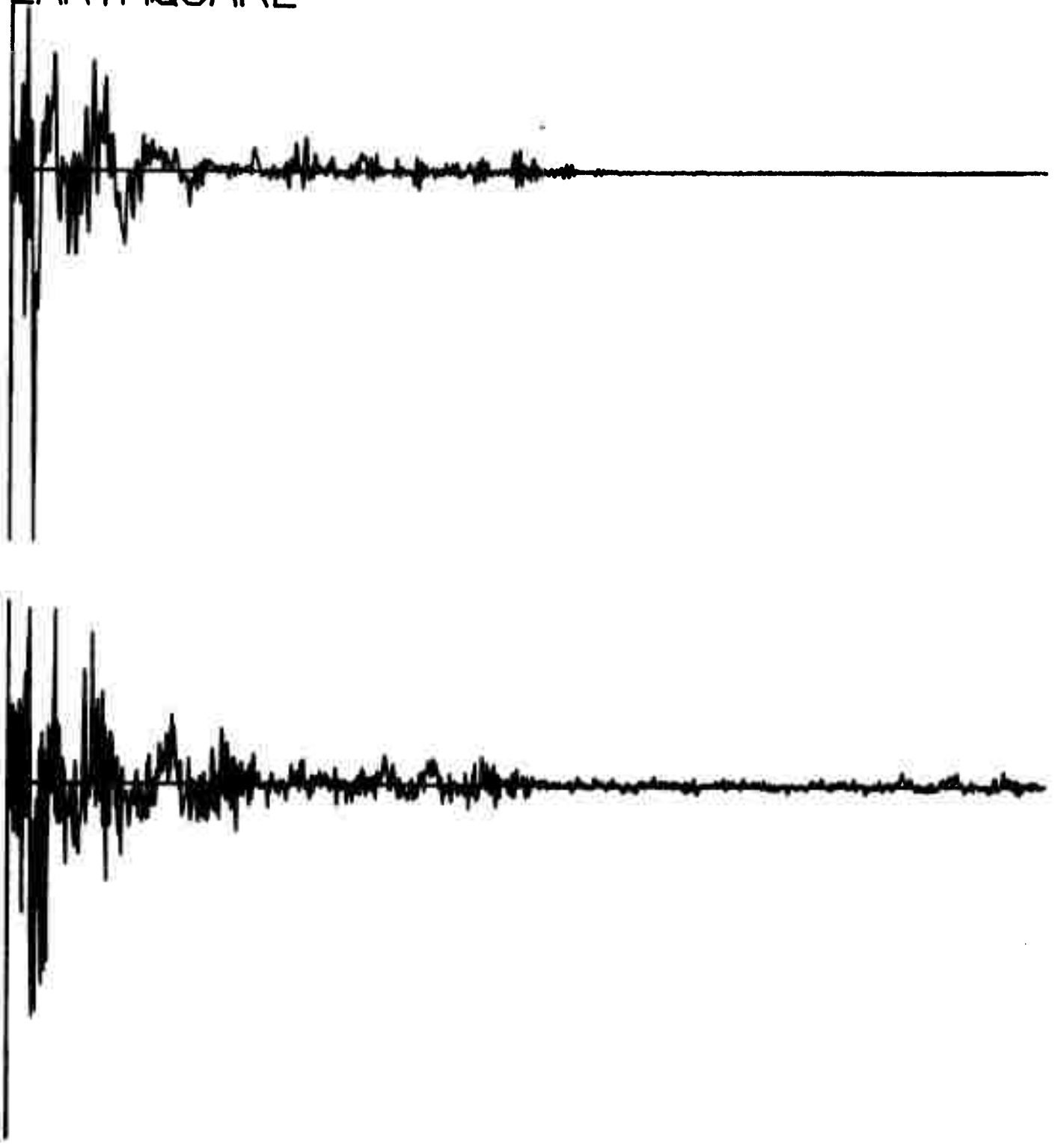
Q156

LVENT NUMBER 1205
EARTHQUAKE

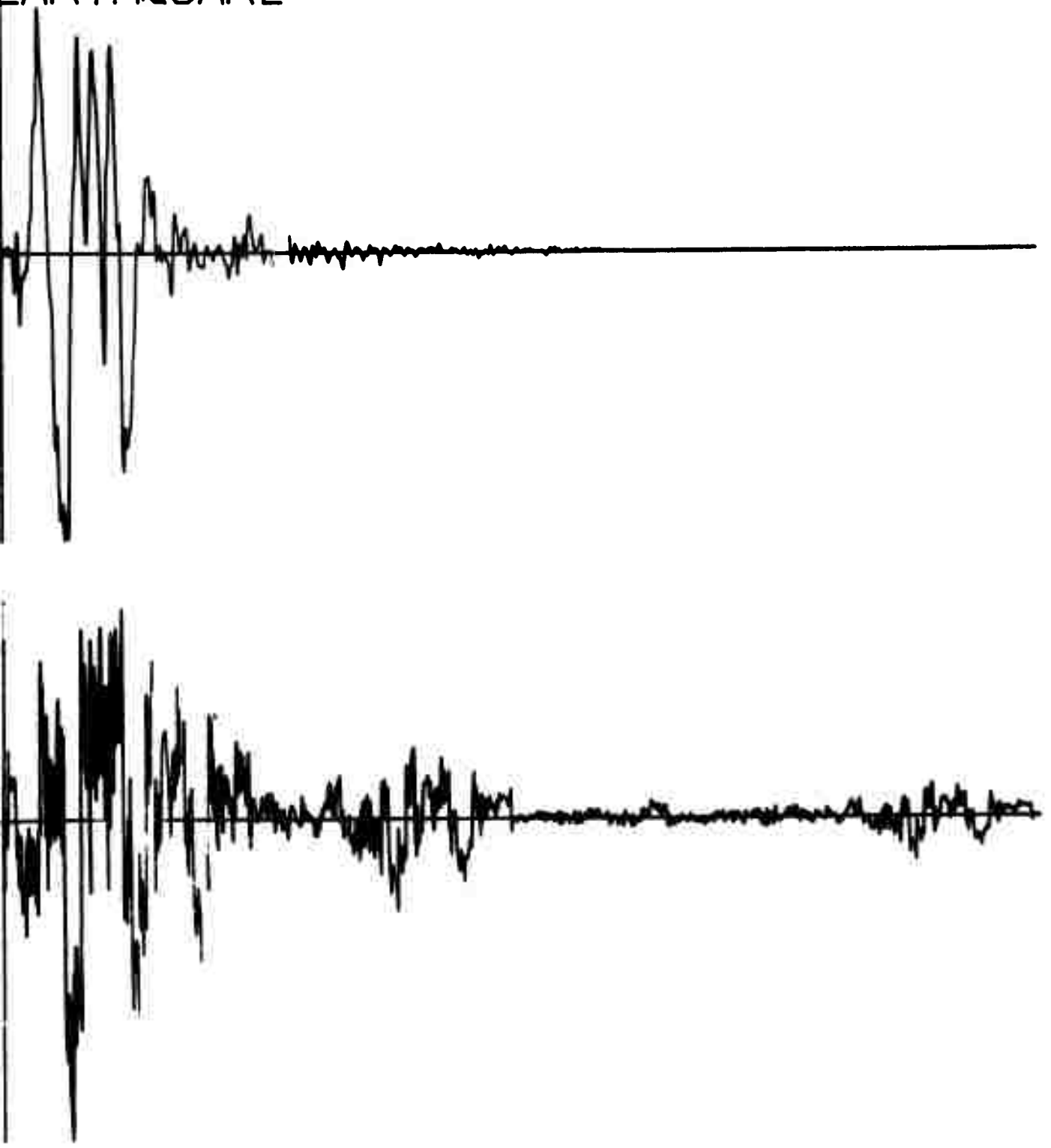


Q158

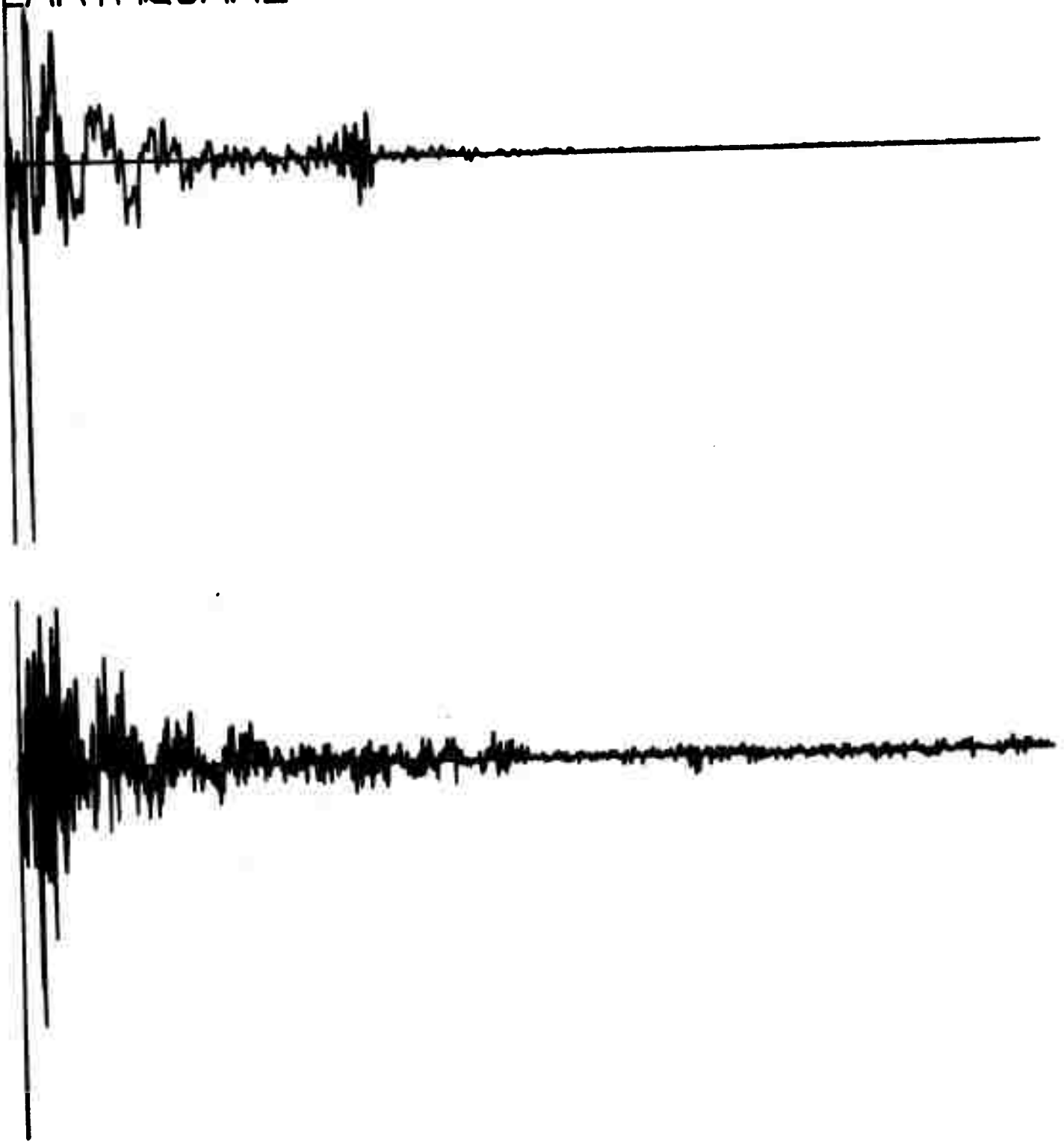
EVENT NUMBER 1207
EARTHQUAKE



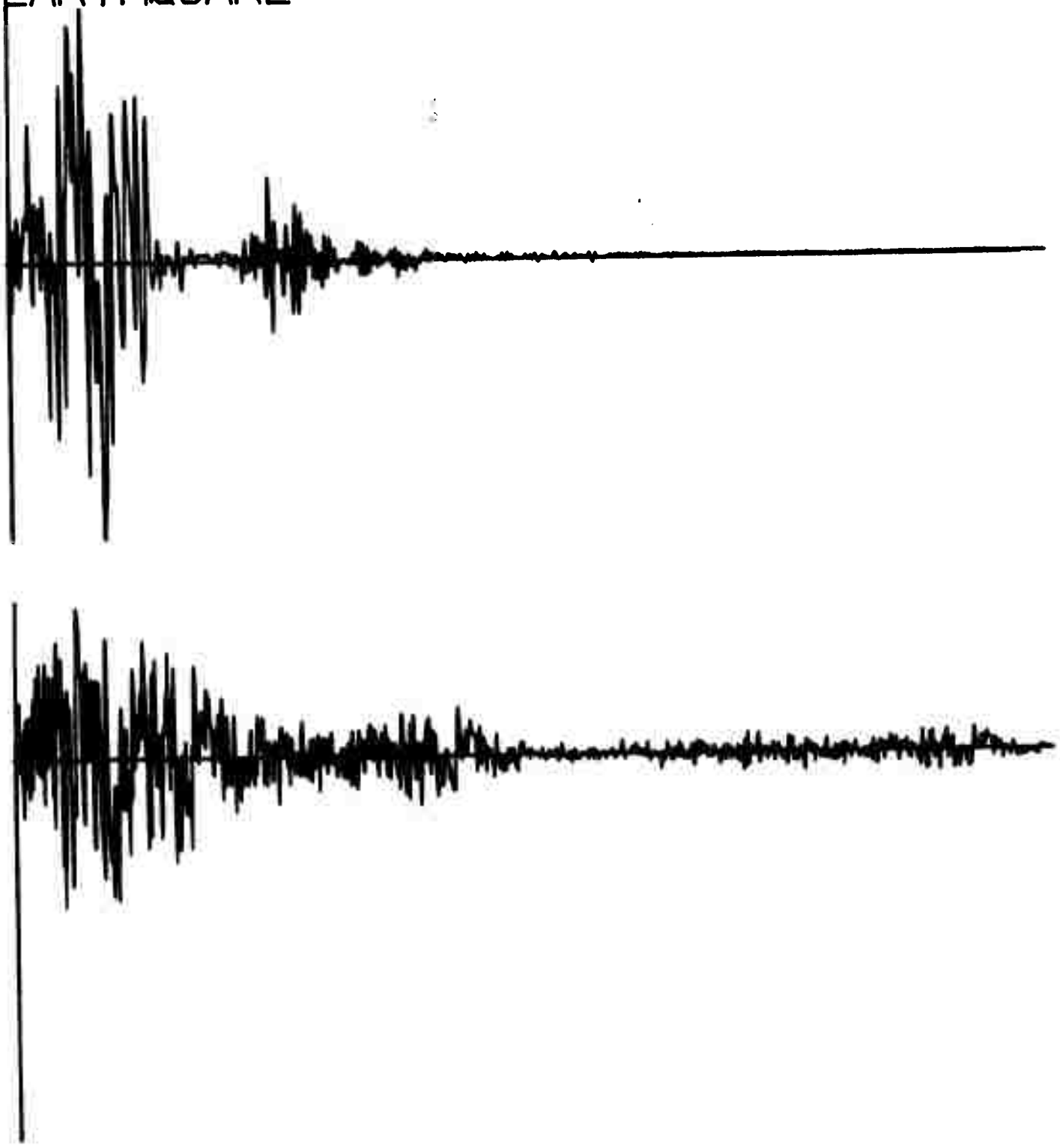
EVENT NUMBER 1209
EARTHQUAKE



EVENT NUMBER 1214
EARTHQUAKE

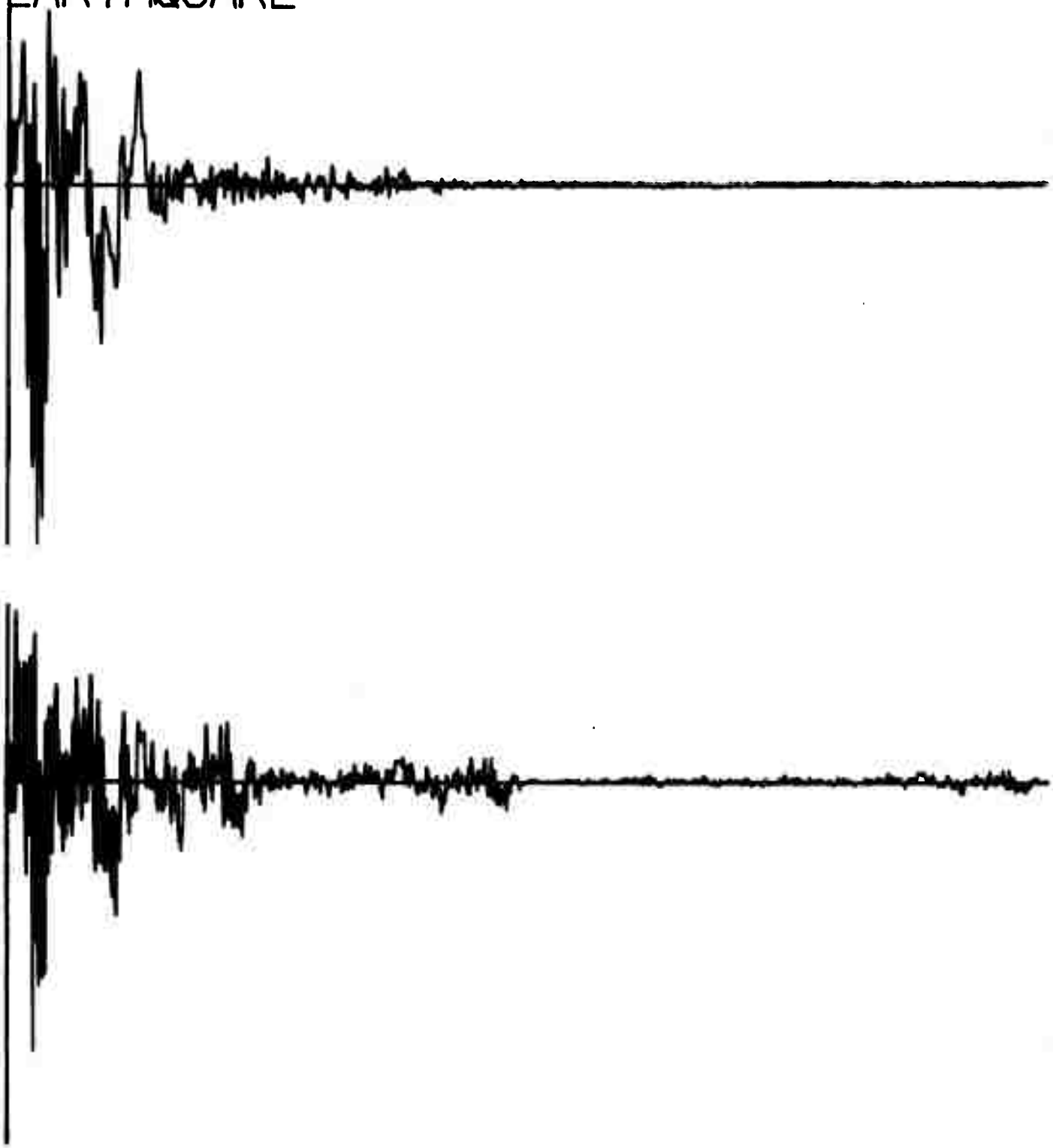


EVENT NUMBER 1250
EARTHQUAKE

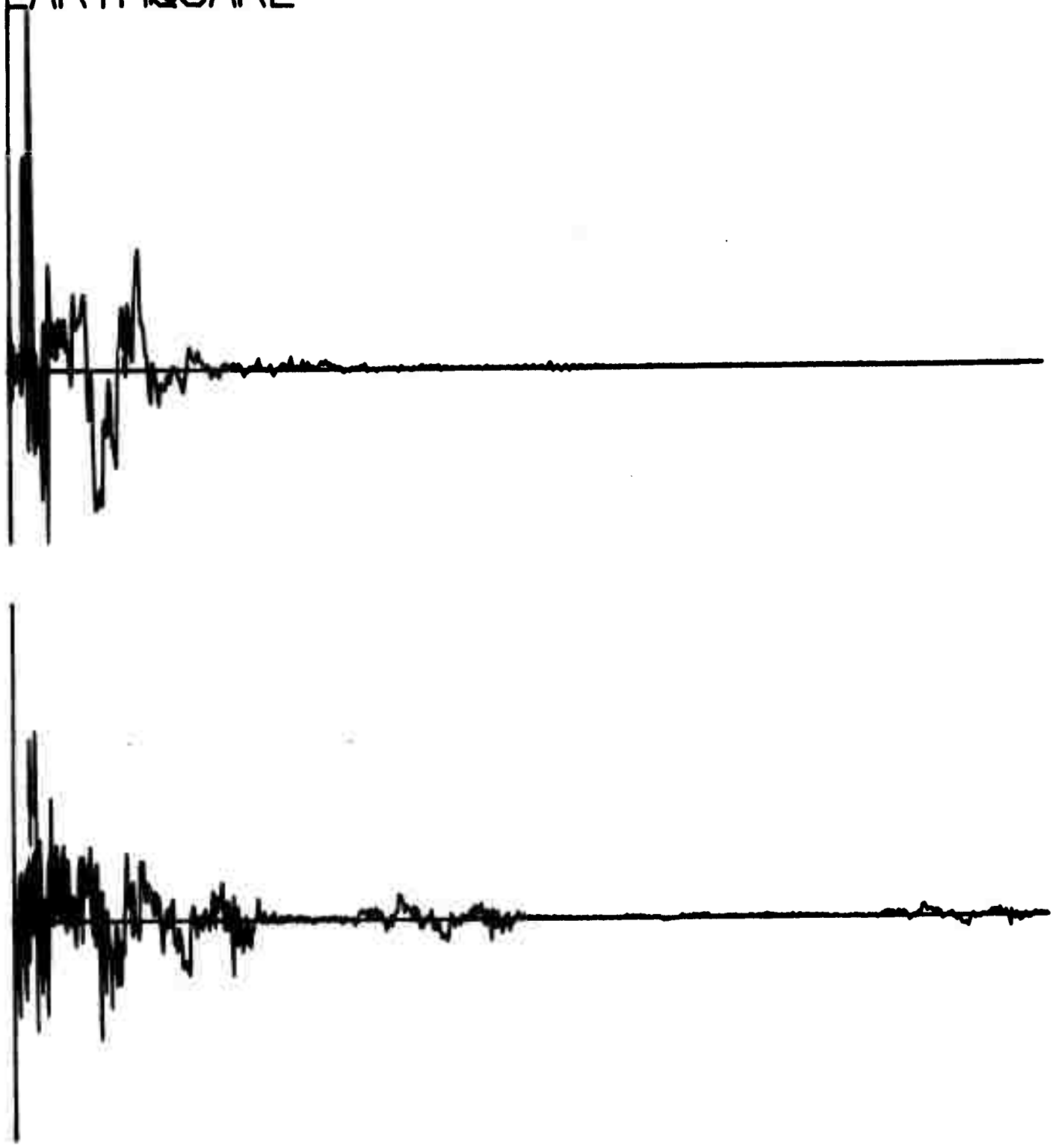


Q166

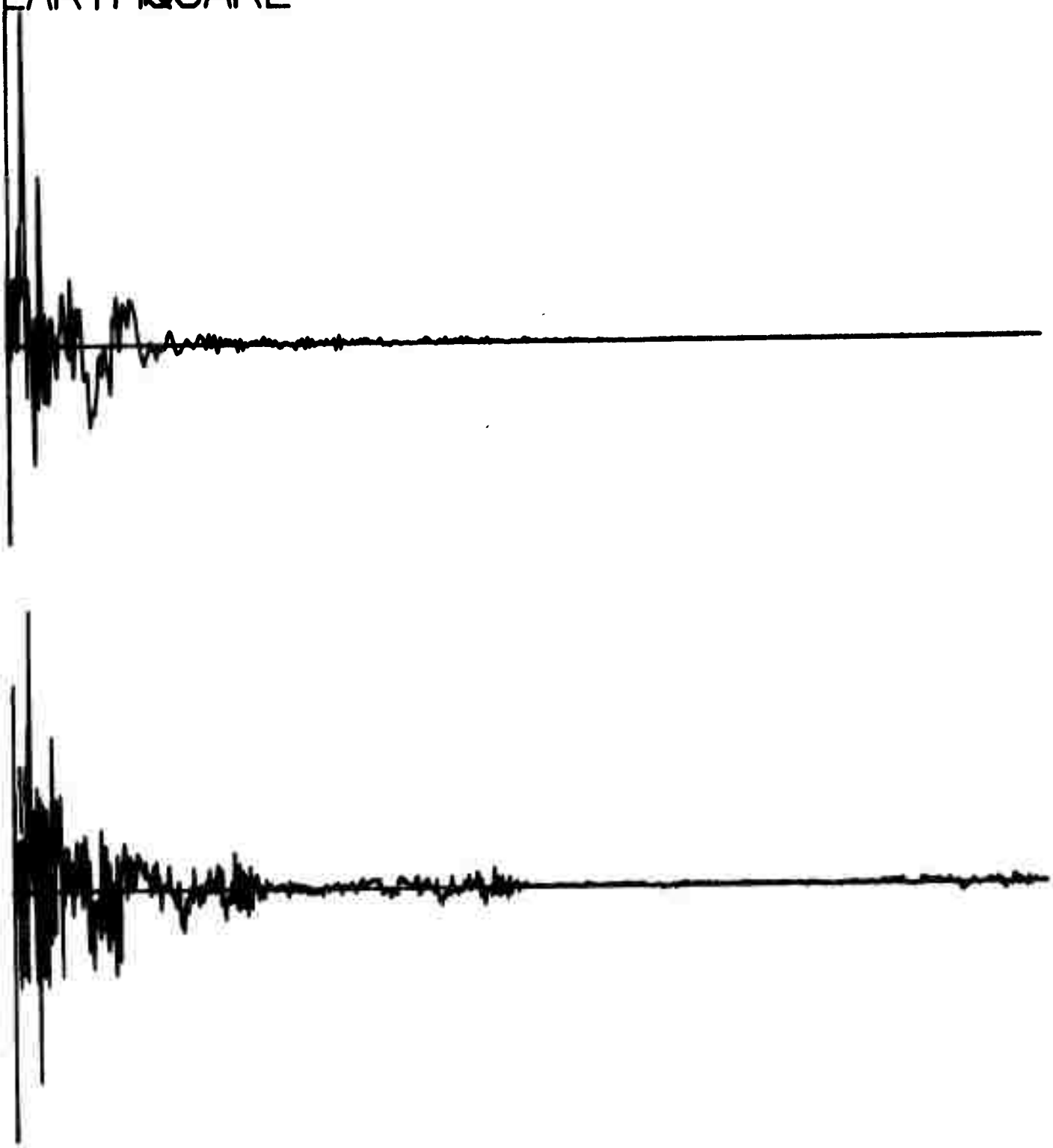
EVENT NUMBER 1224
EARTHQUAKE



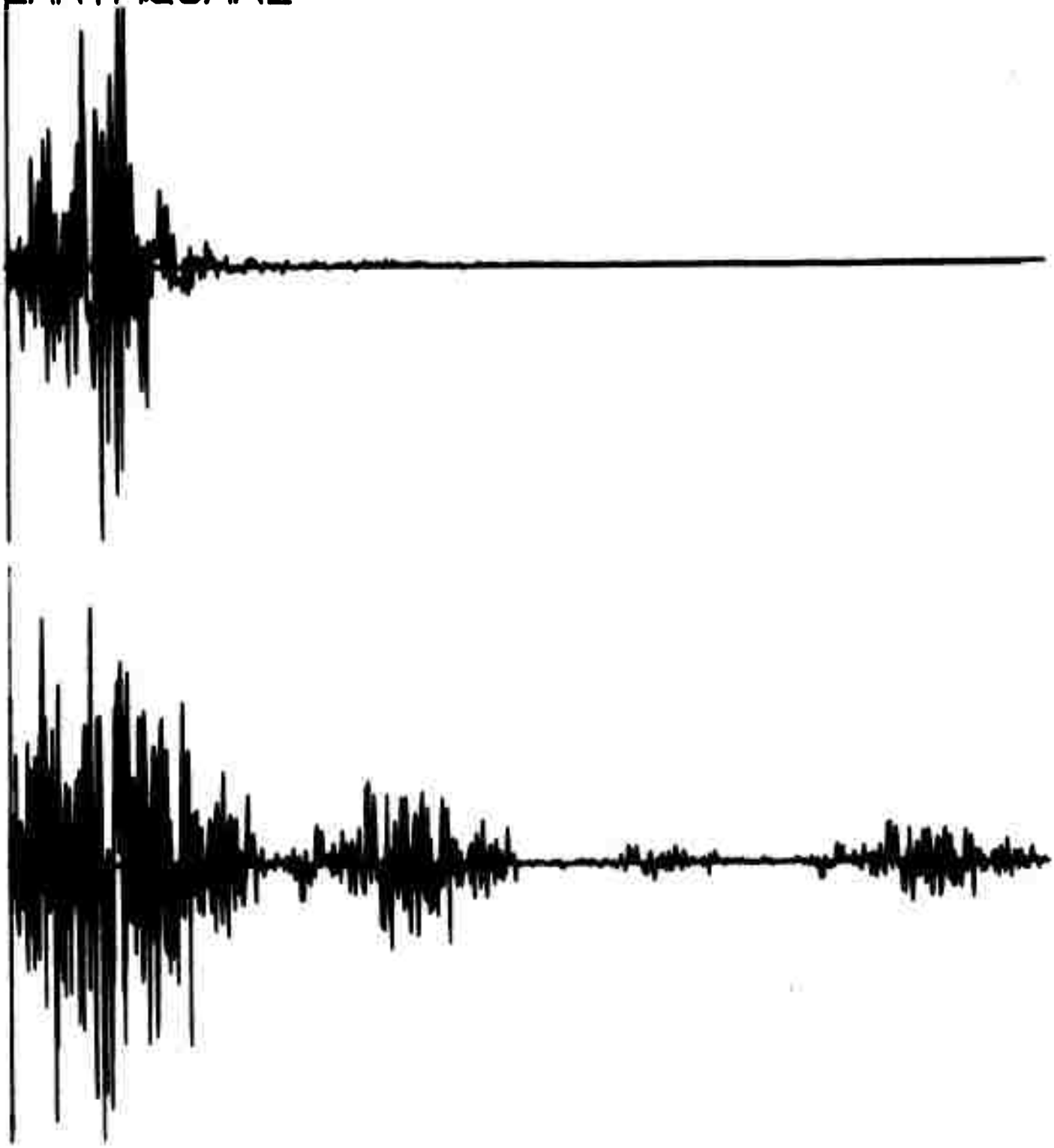
L. VENT NUMBER 1223
EARTHQUAKE



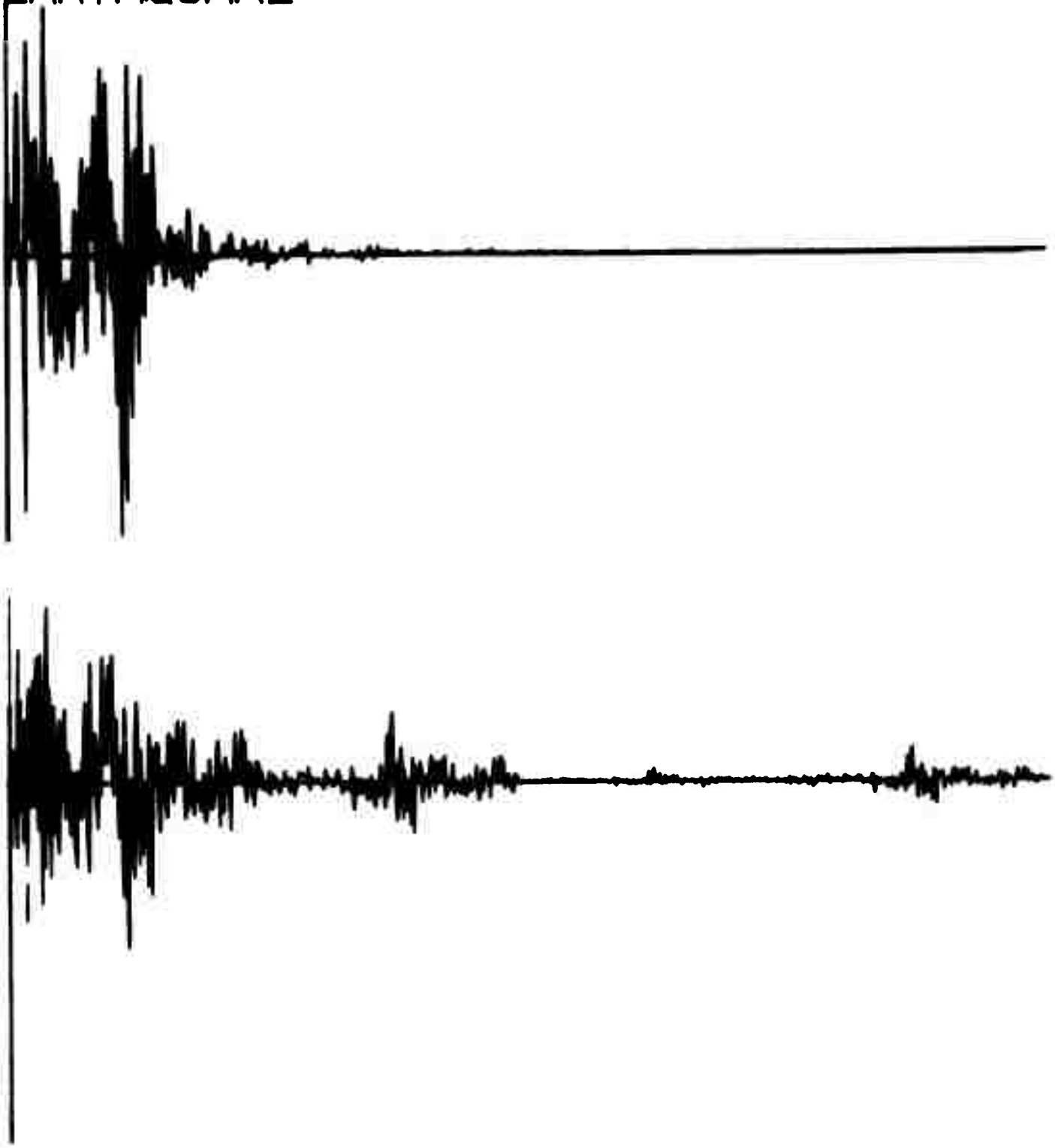
I VENT NUMBER 1222
EARTHQUAKE



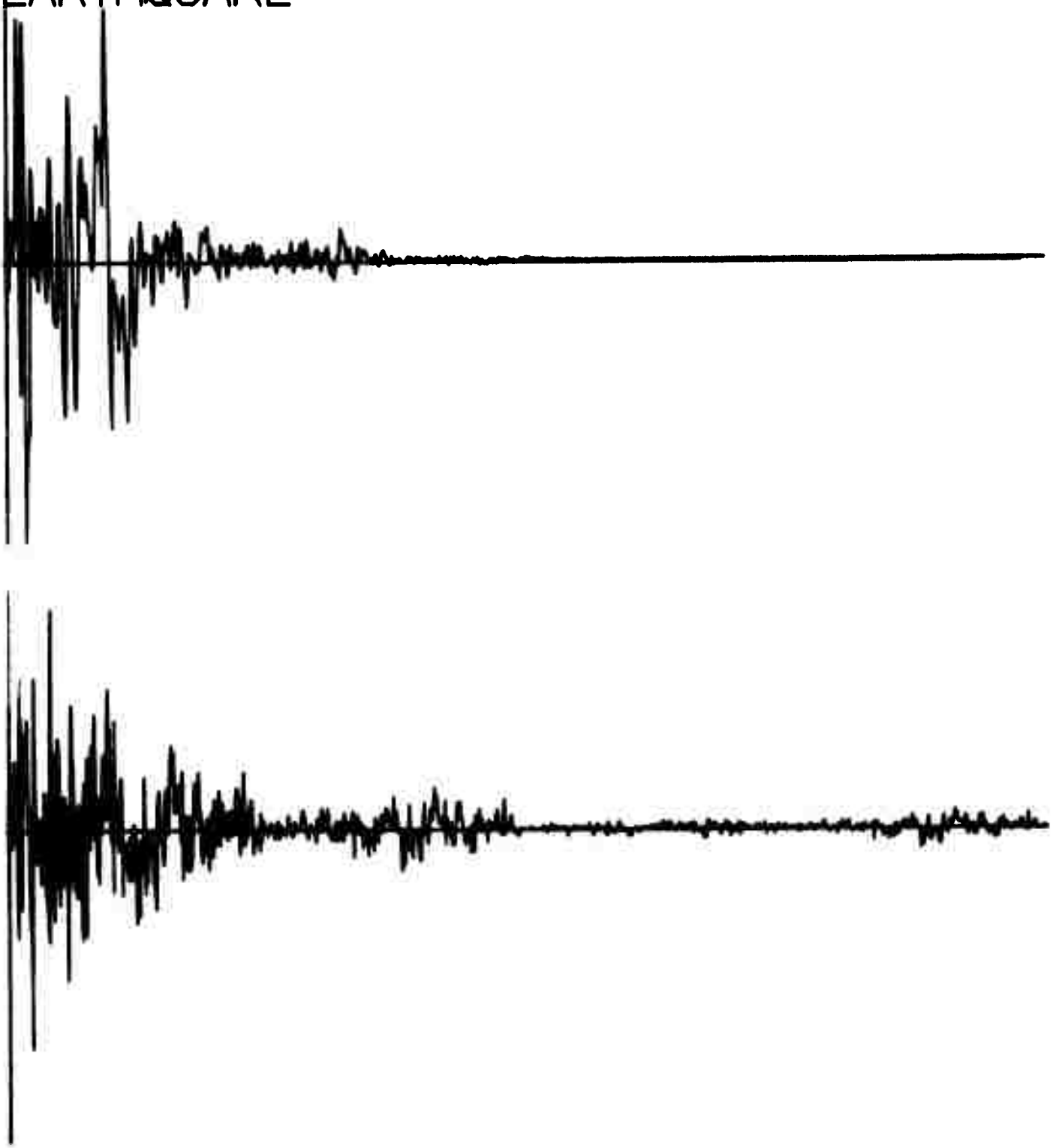
LVENT NUMBER 1035
EARTHQUAKE



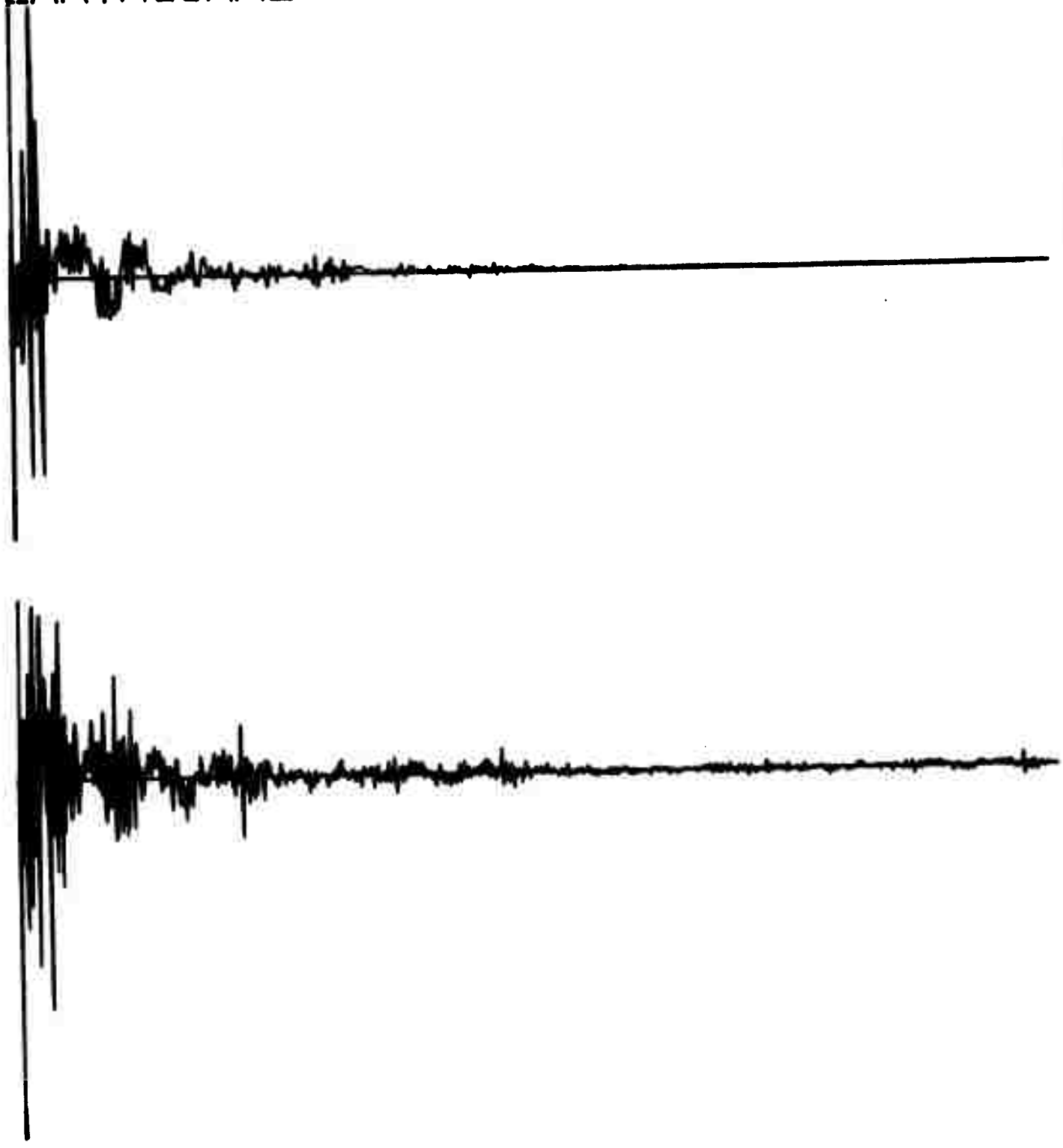
EVENT NUMBER 1032
EARTHQUAKE



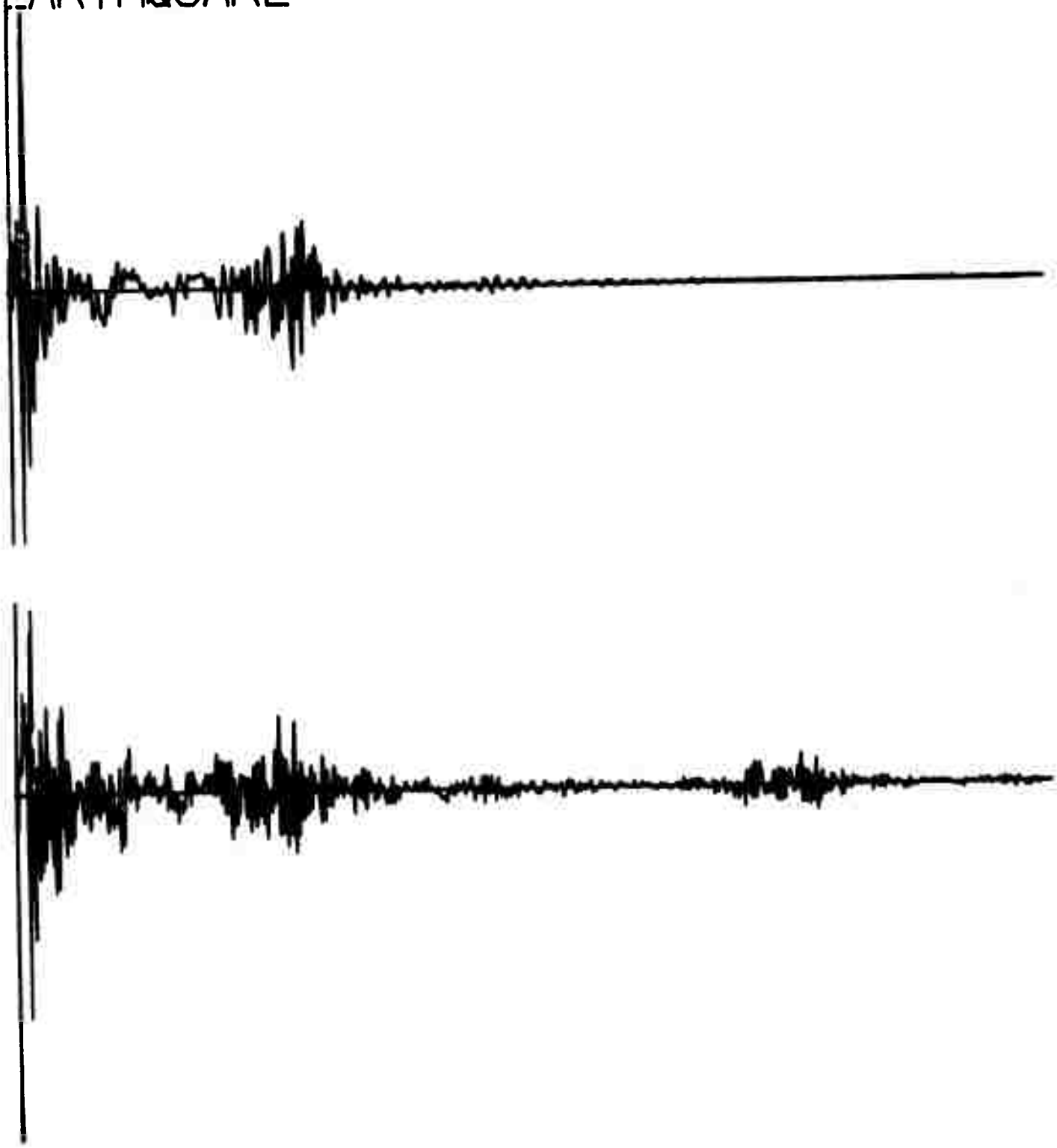
VENT NUMBER 1Ø28
EARTHQUAKE



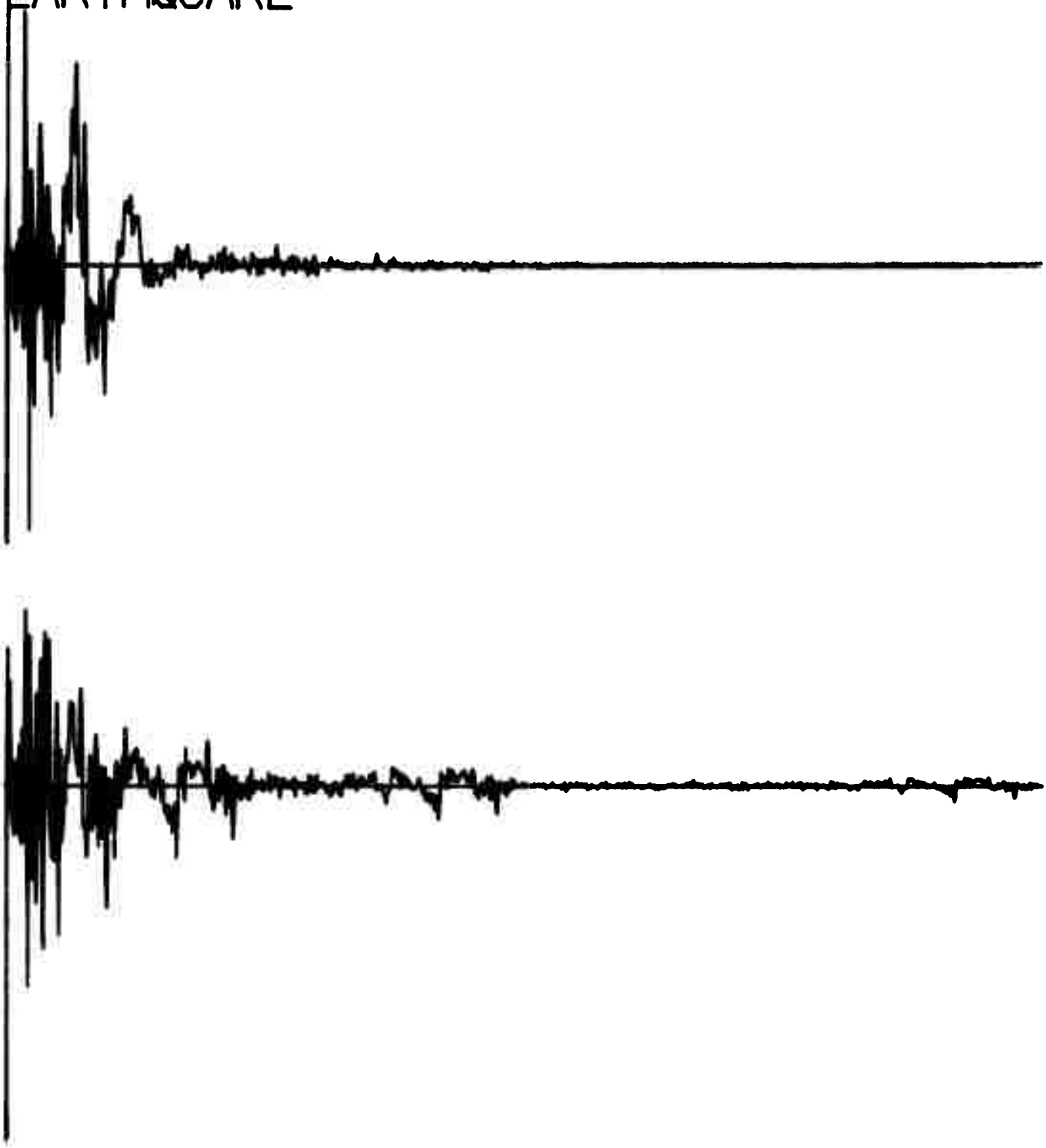
EVENT NUMBER 1027
EARTHQUAKE



EVENT NUMBER 1025
EARTHQUAKE

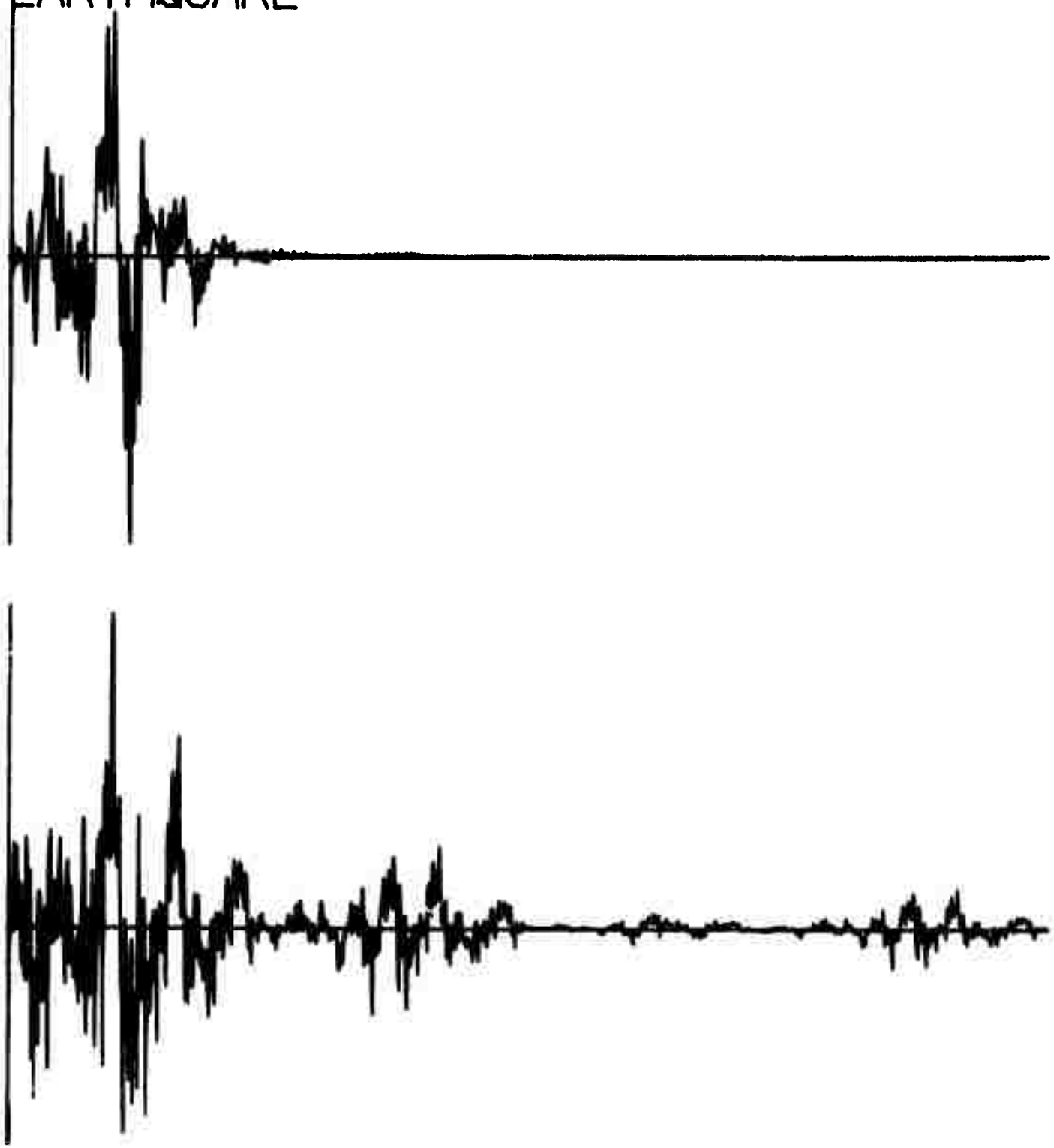


EVENT NUMBER 1019
EARTHQUAKE

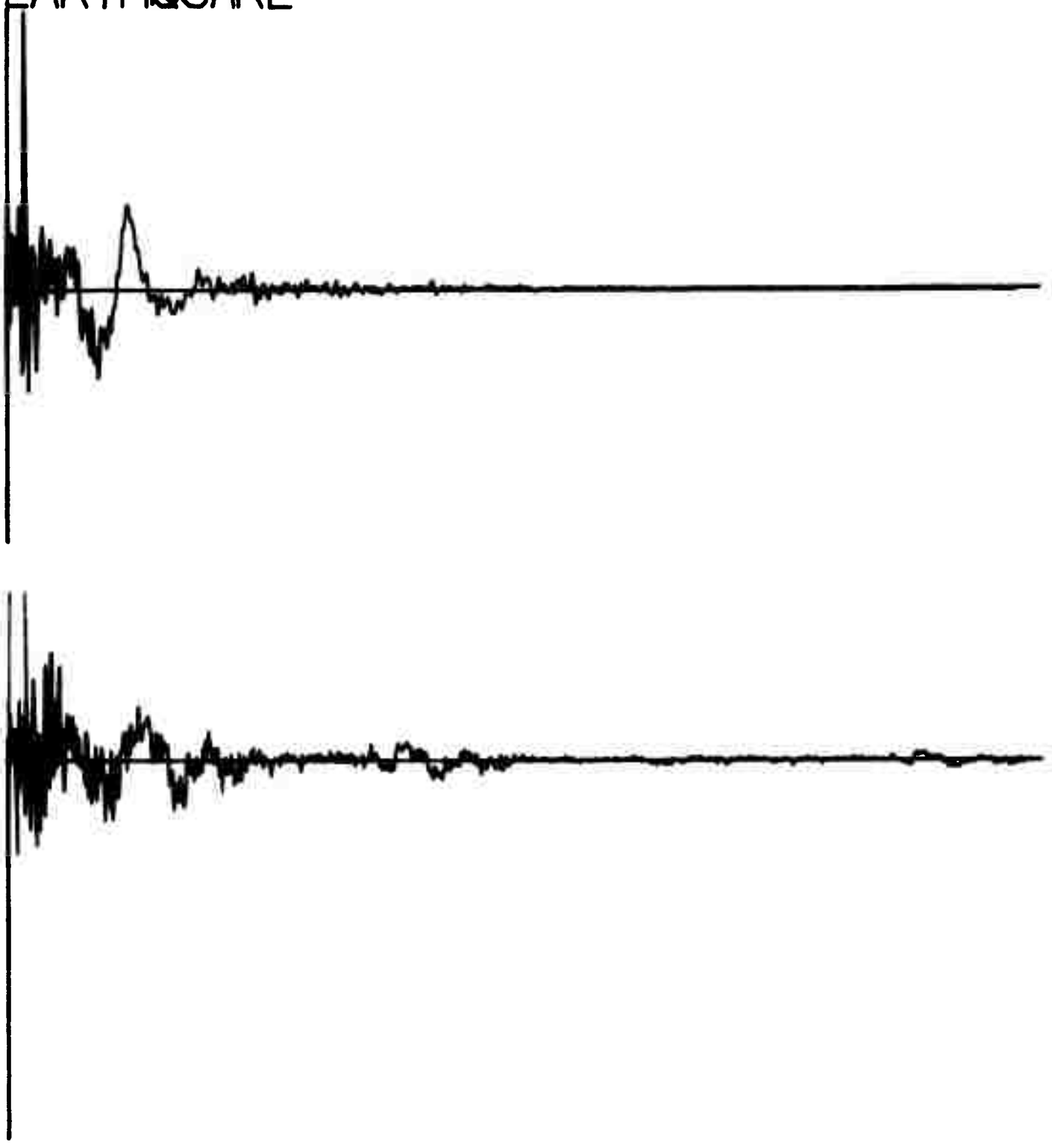


Q184

EVENT NUMBER 1003
EARTHQUAKE

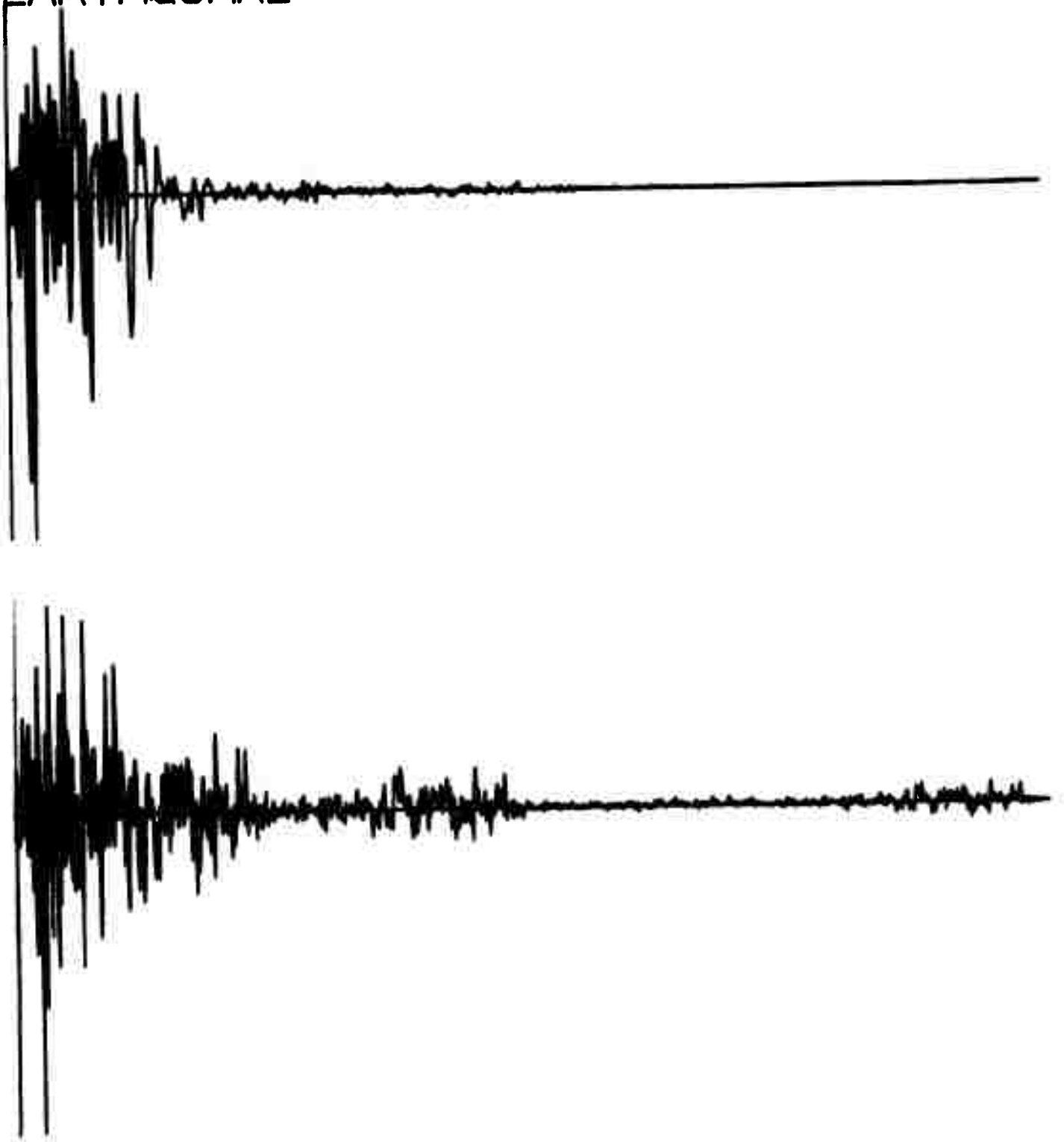


EVENT NUMBER 1002
EARTHQUAKE

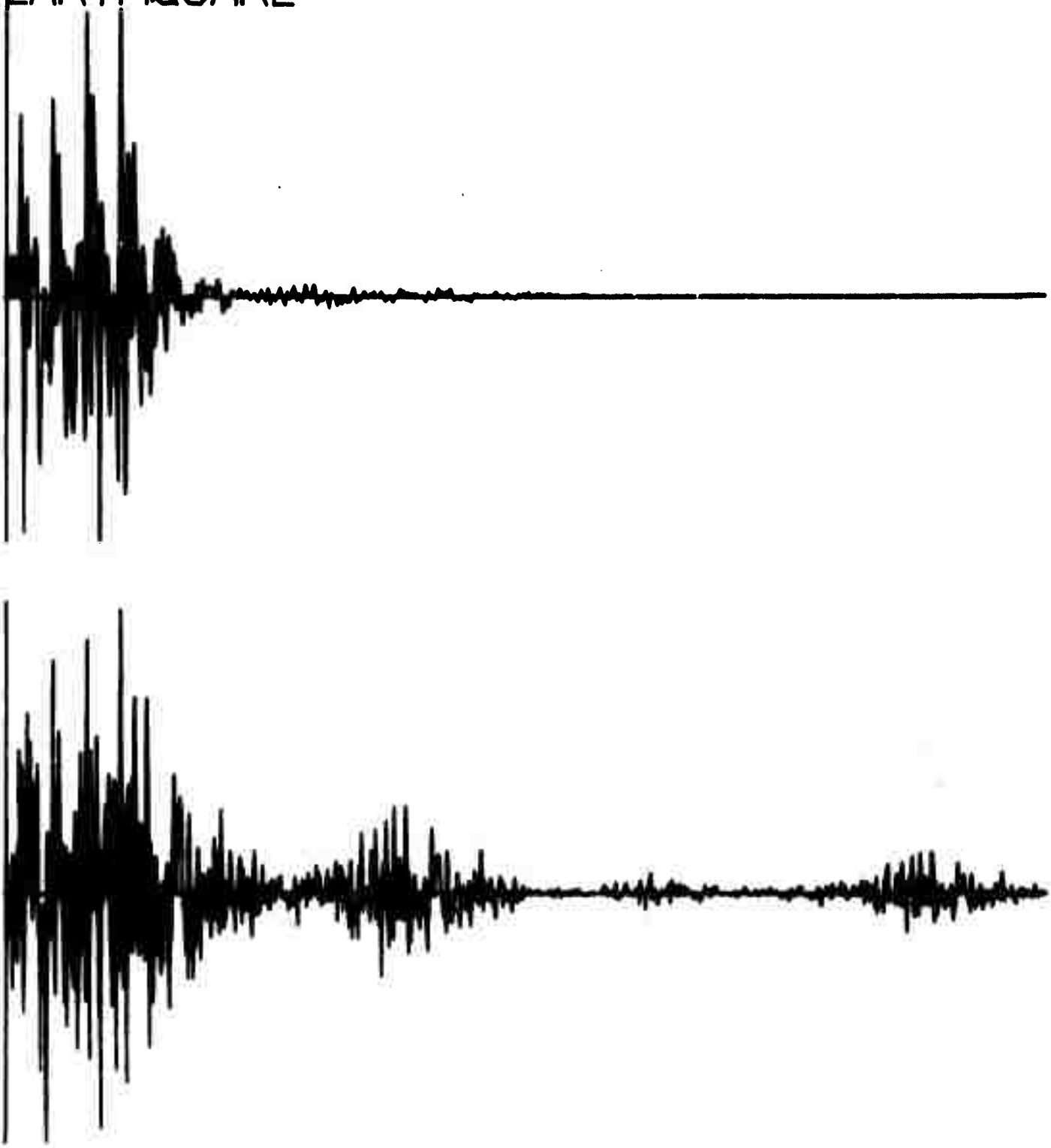


Q188

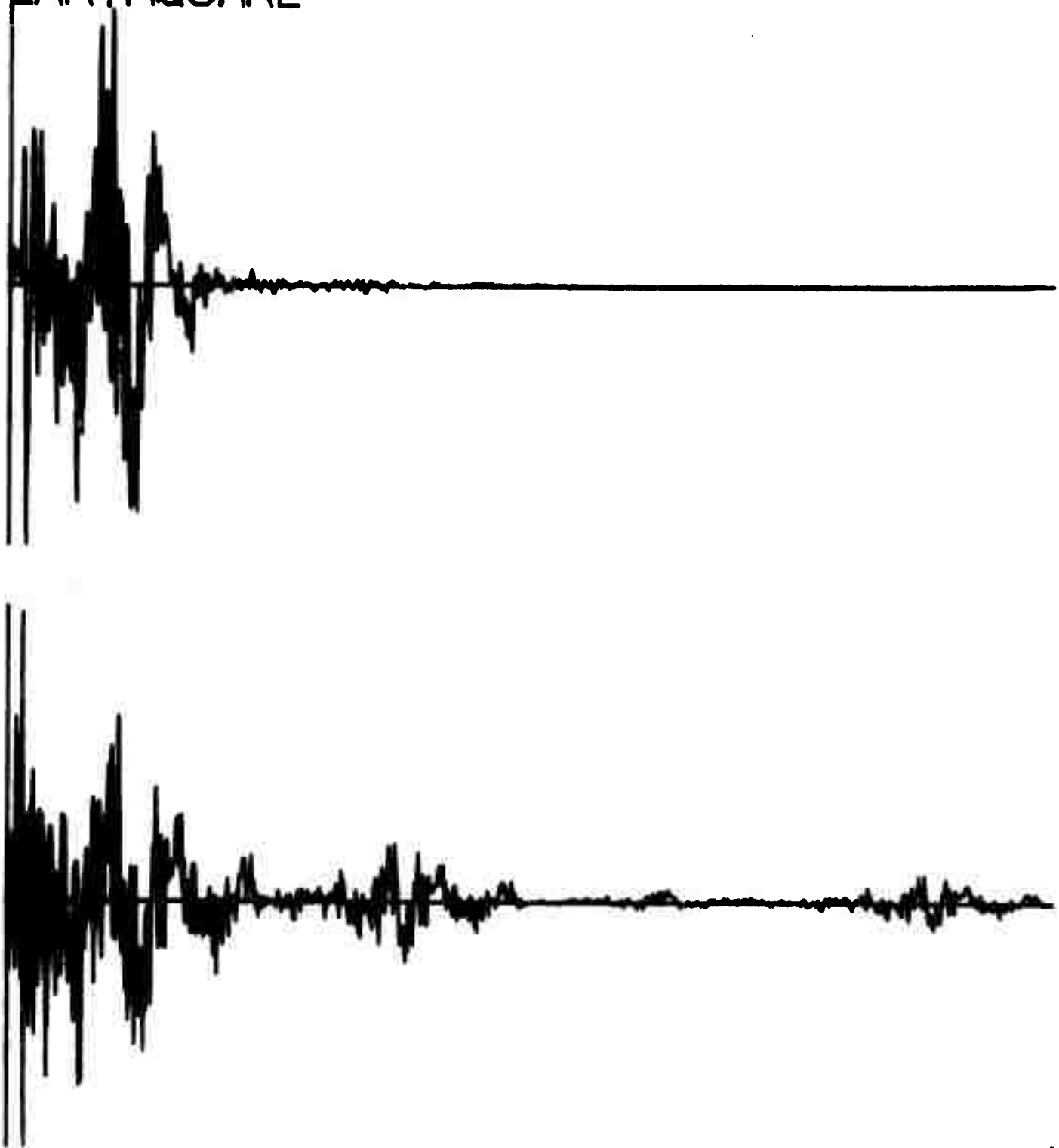
EVENT NUMBER 1096
EARTHQUAKE



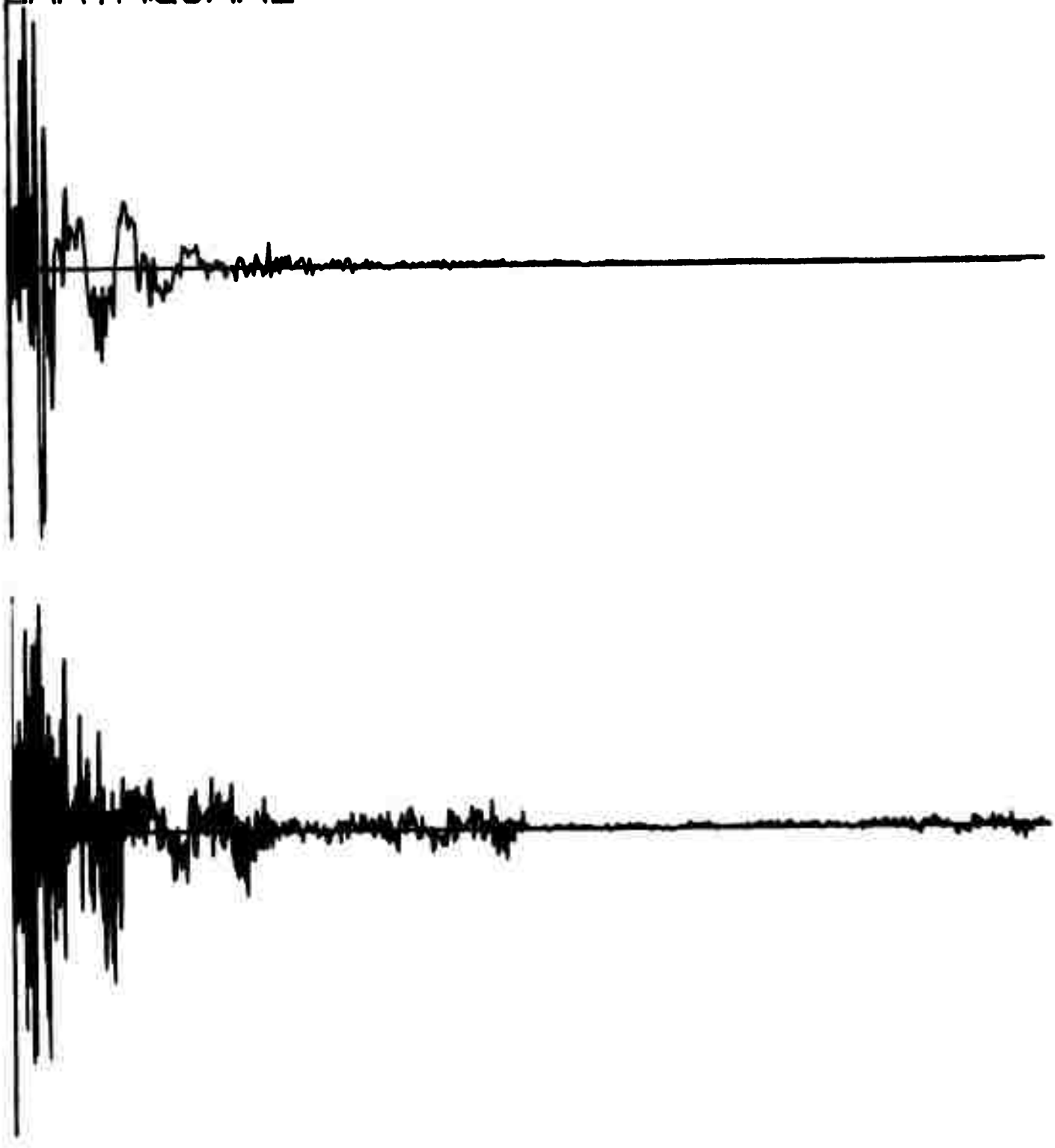
EVENT NUMBER 1093
EARTHQUAKE



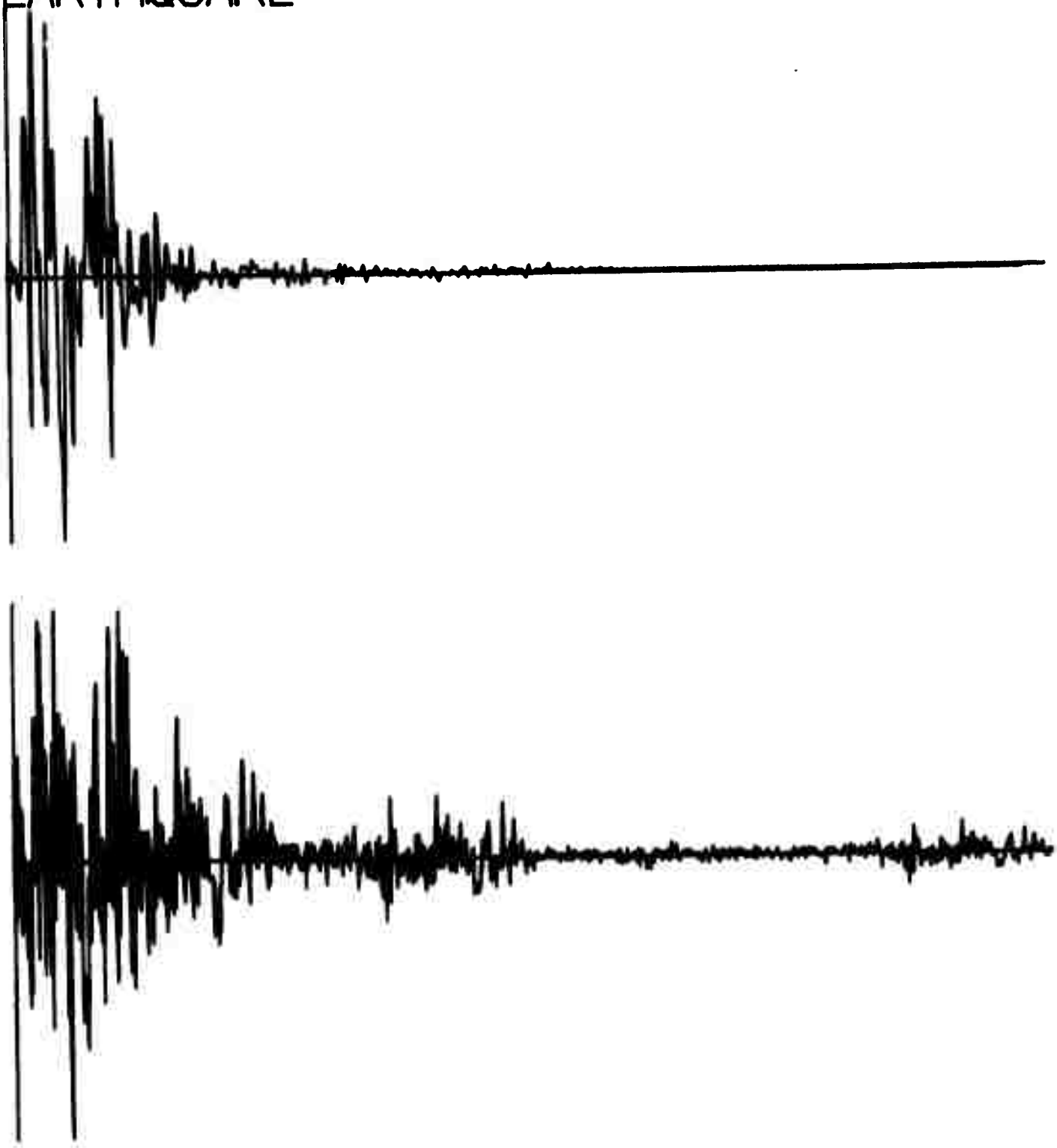
VENT NUMBER 1092
EARTHQUAKE



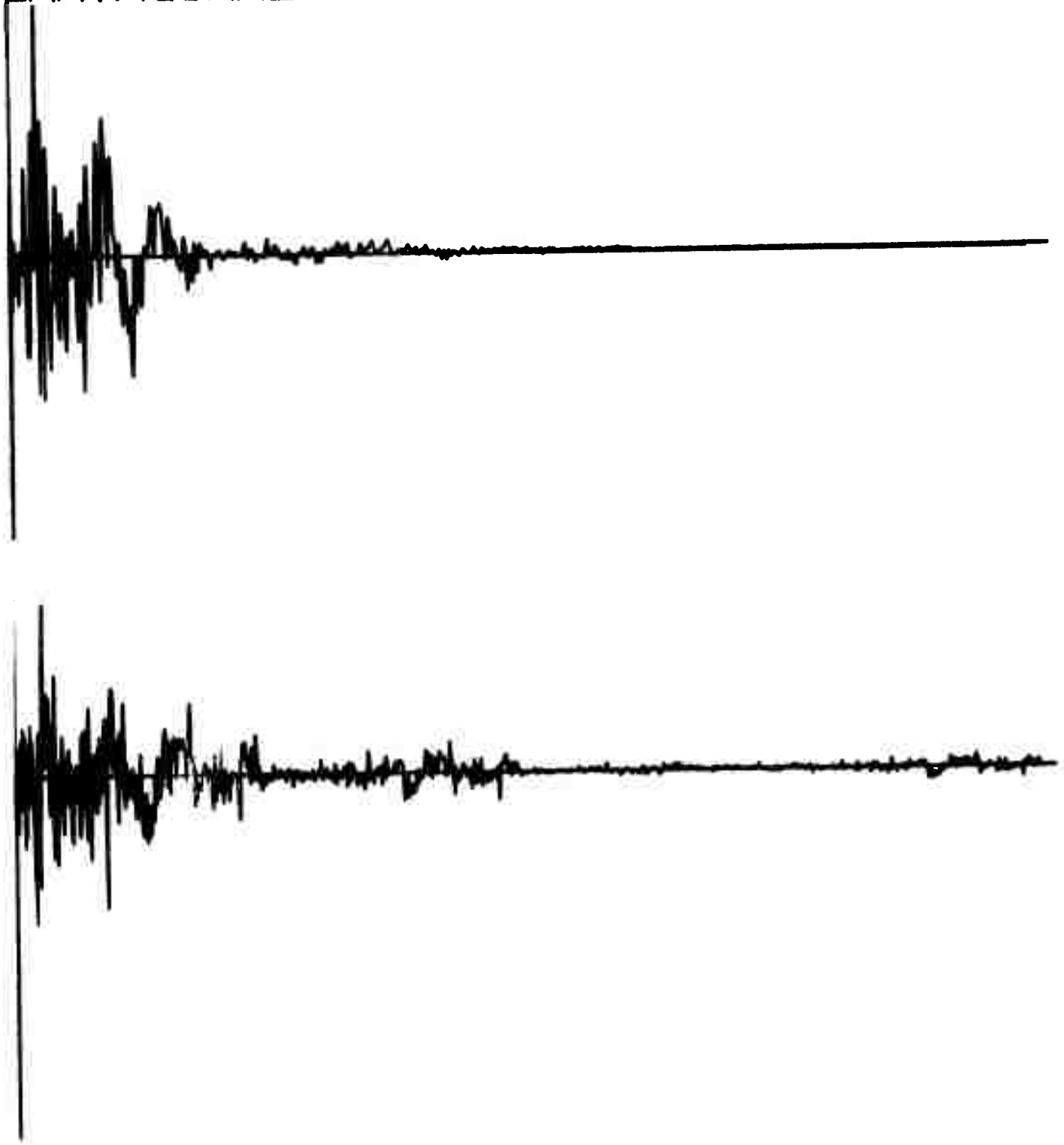
EVENT NUMBER 1069
EARTHQUAKE



VENT NUMBER 1051
EARTHQUAKE



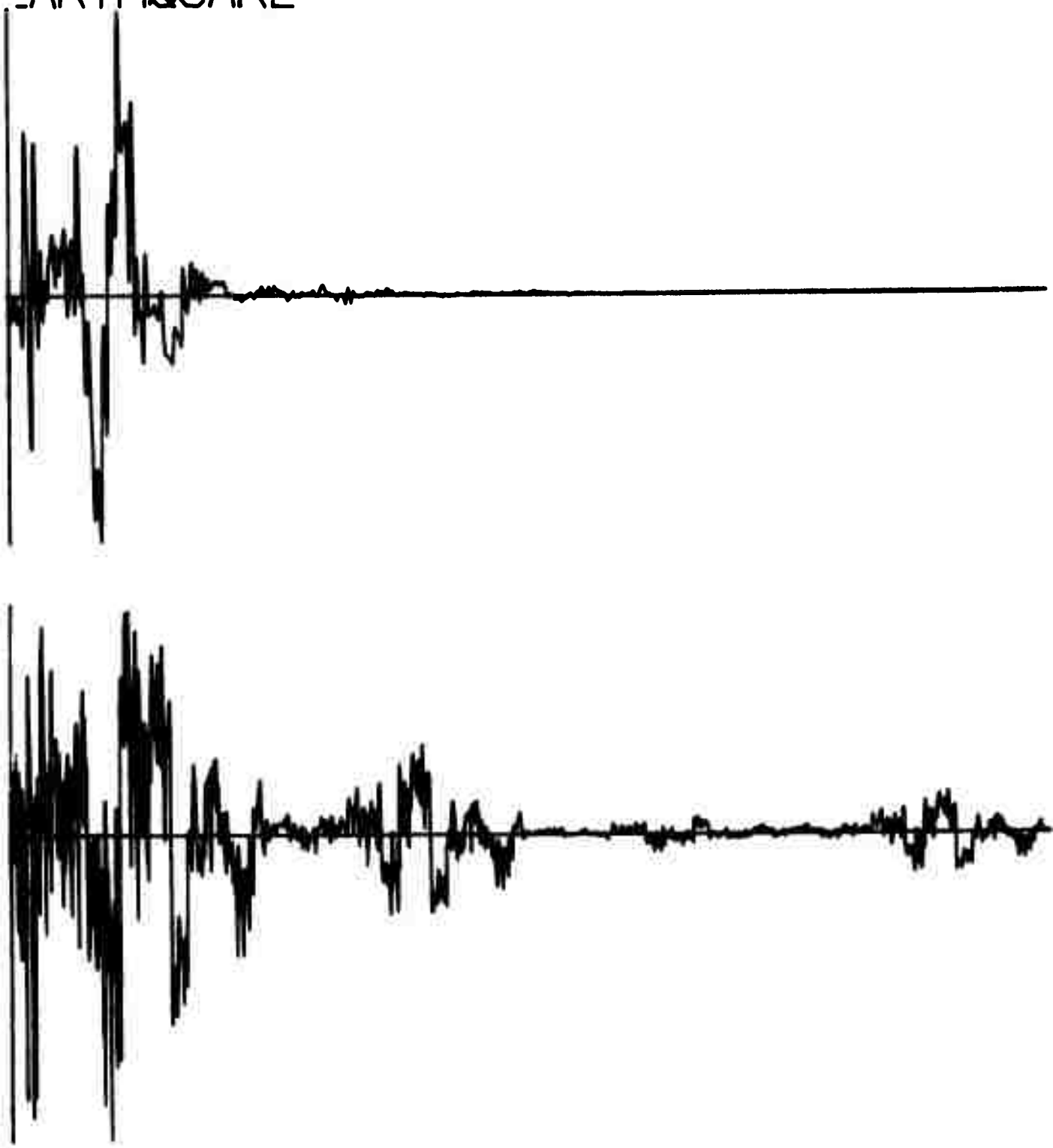
VENT NUMBER 1045
EARTHQUAKE



Q200

VENT NUMBER 1189

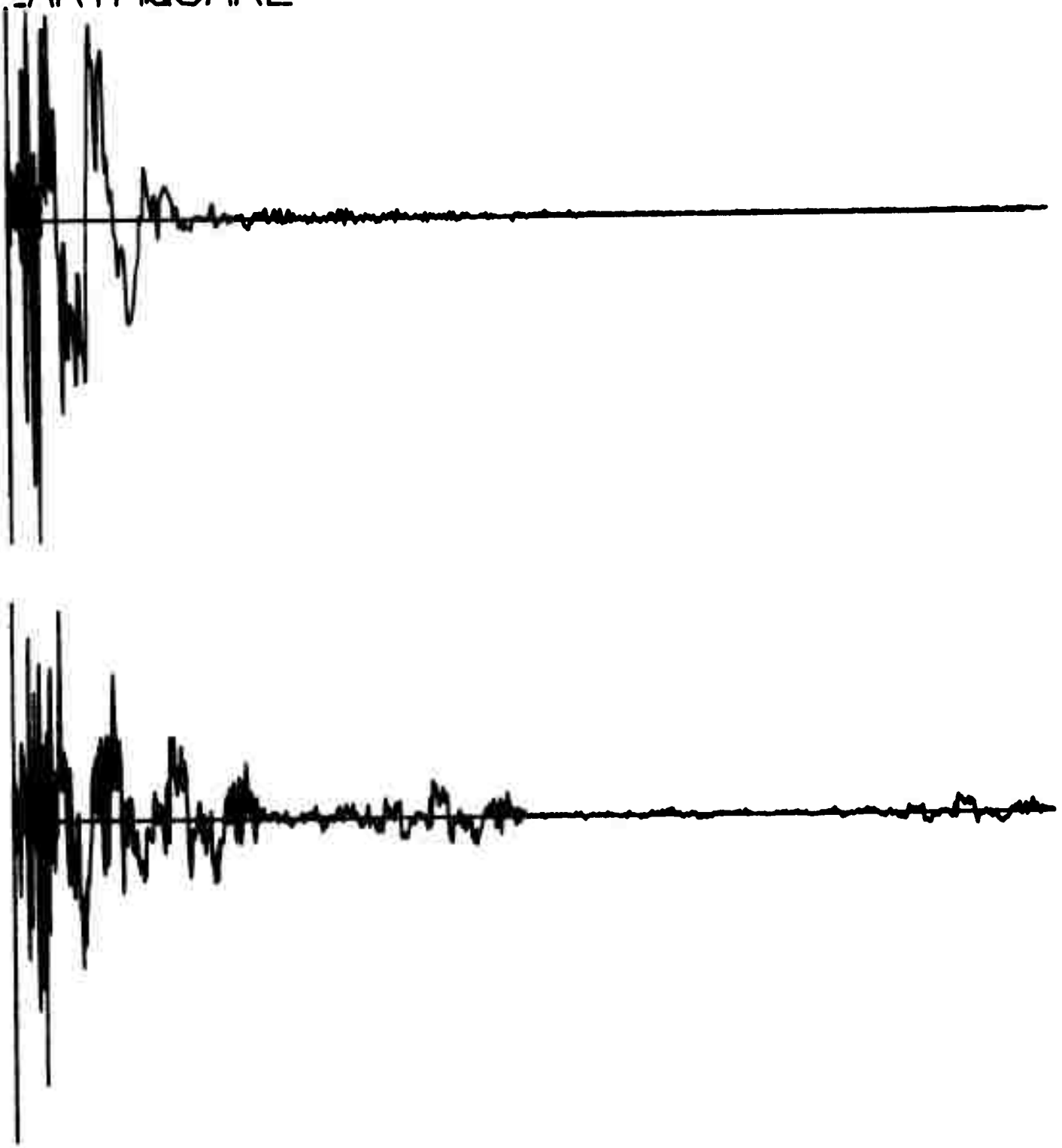
EARTHQUAKE



Q202

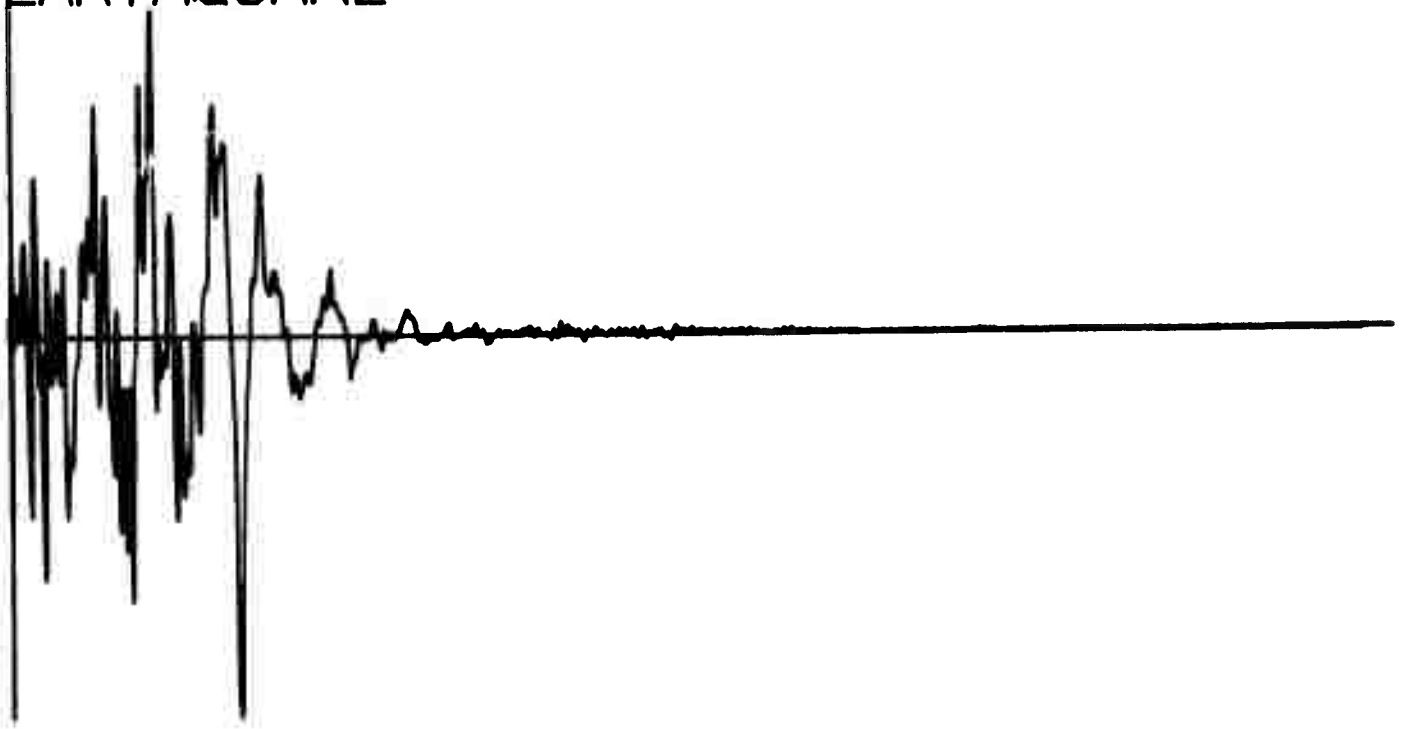
VENT NUMBER 1197

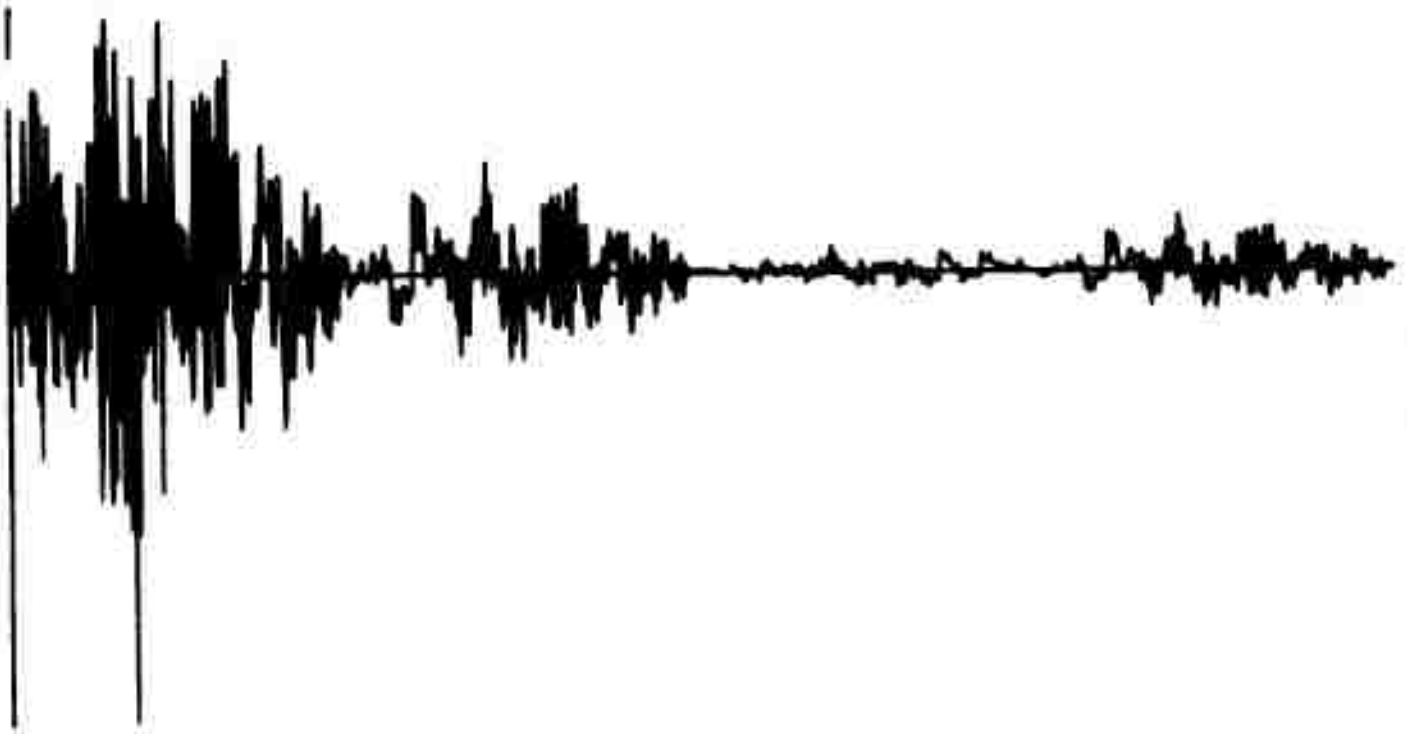
EARTHQUAKE



Q204

VENT NUMBER 1211
EARTHQUAKE

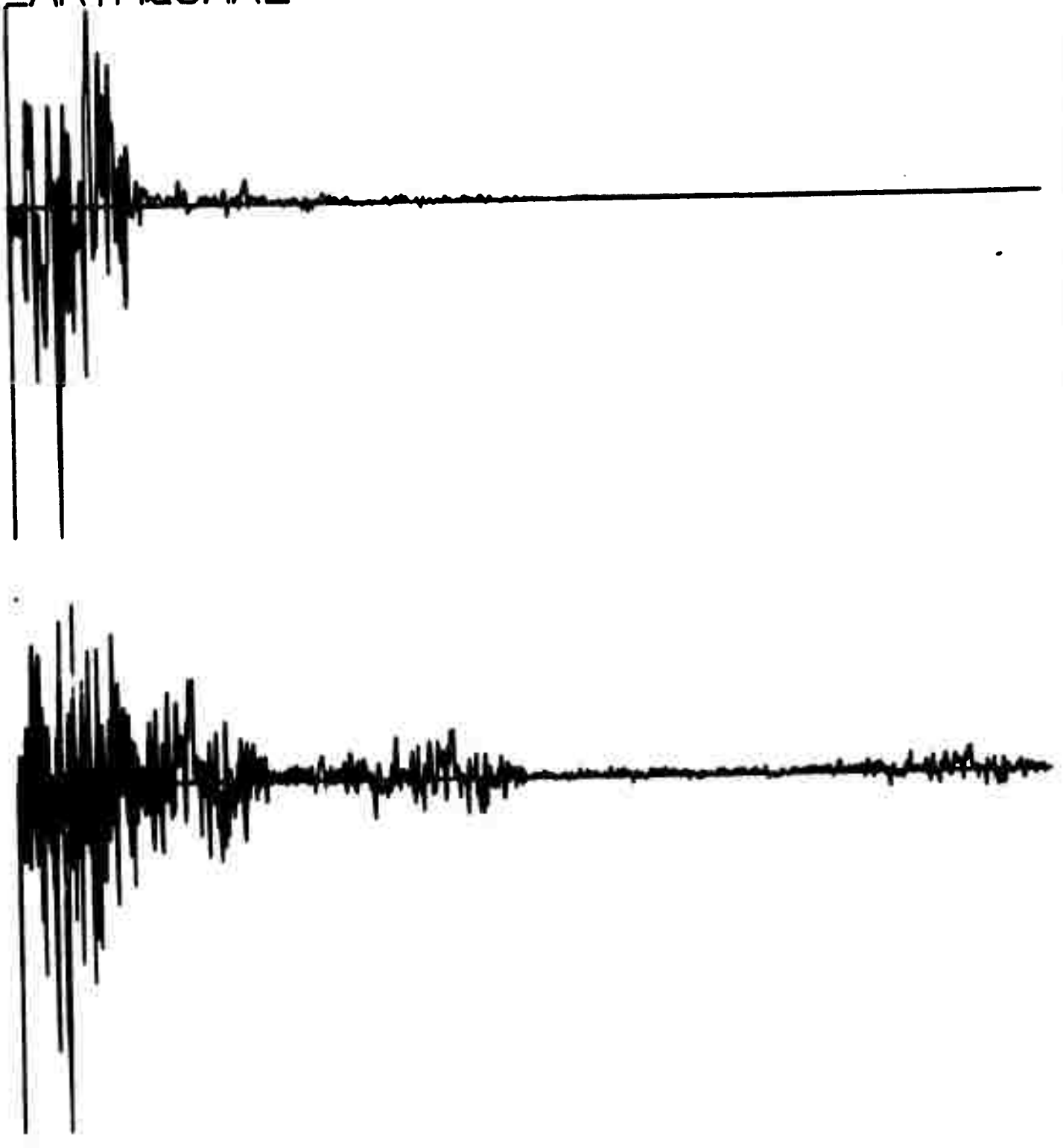




Q206

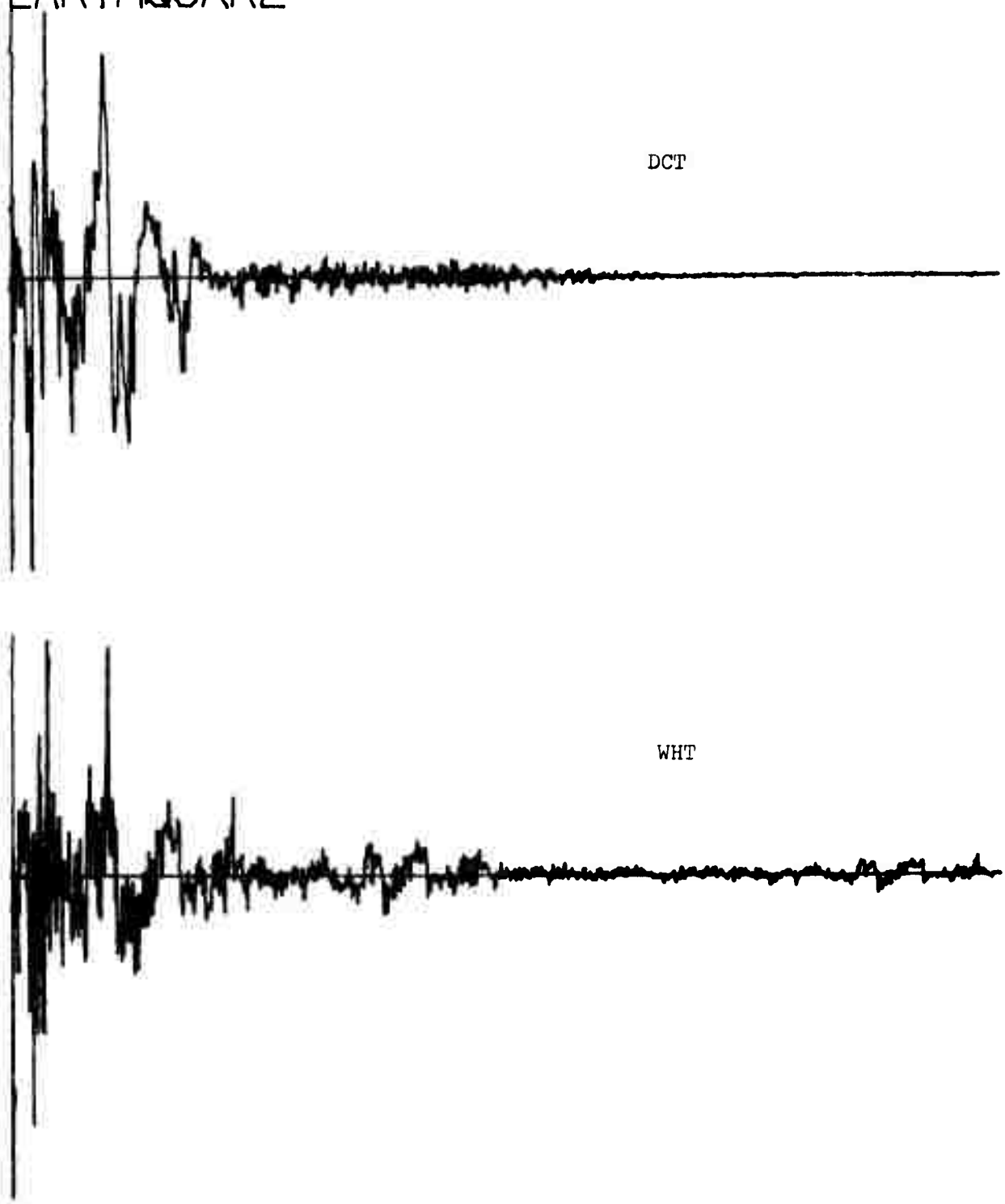
EVENT NUMBER 1212

EARTHQUAKE



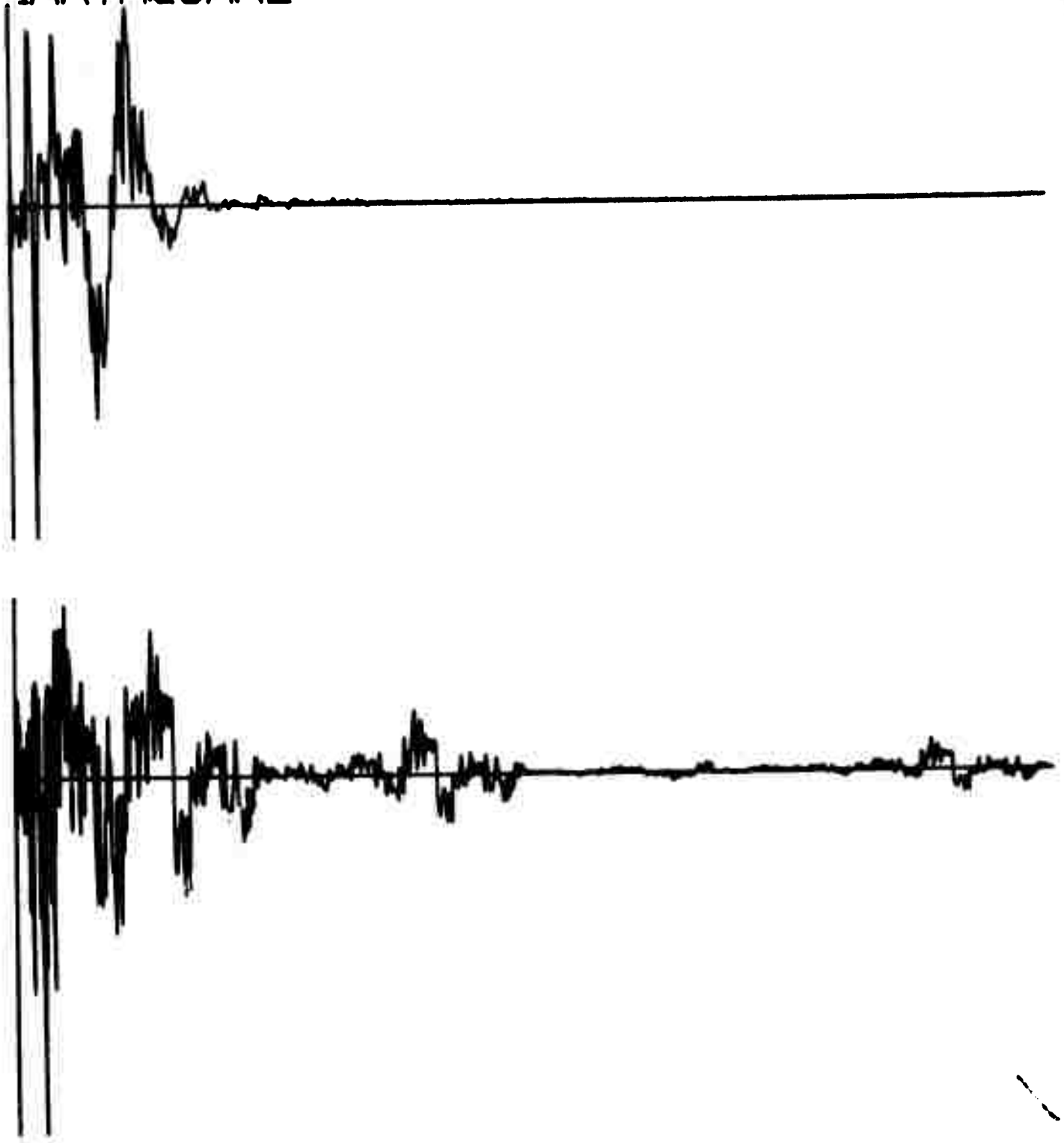
Q208

EVENT NUMBER 1213
EARTHQUAKE



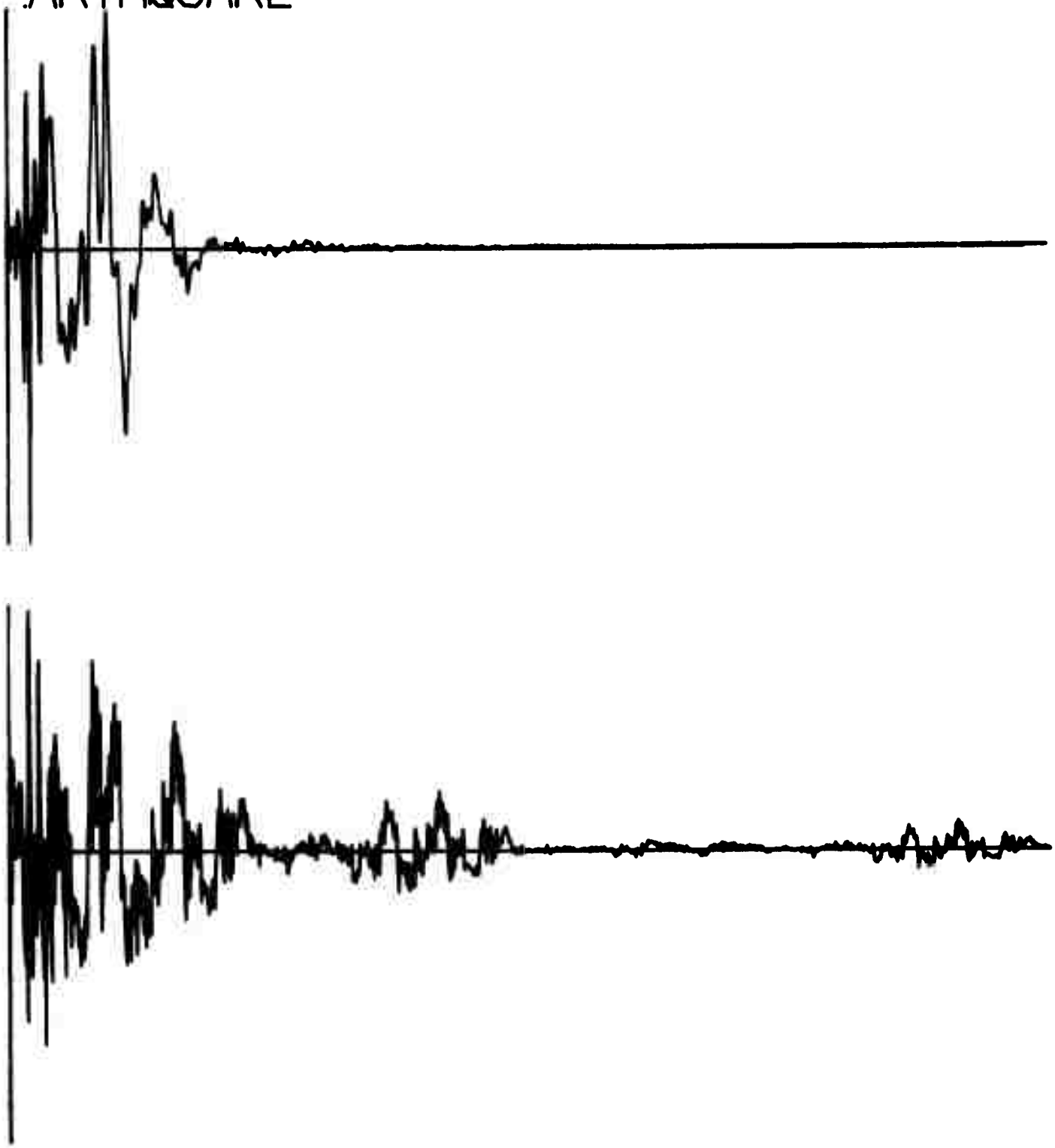
Q210

VENT NUMBER 1228
EARTHQUAKE



Q212

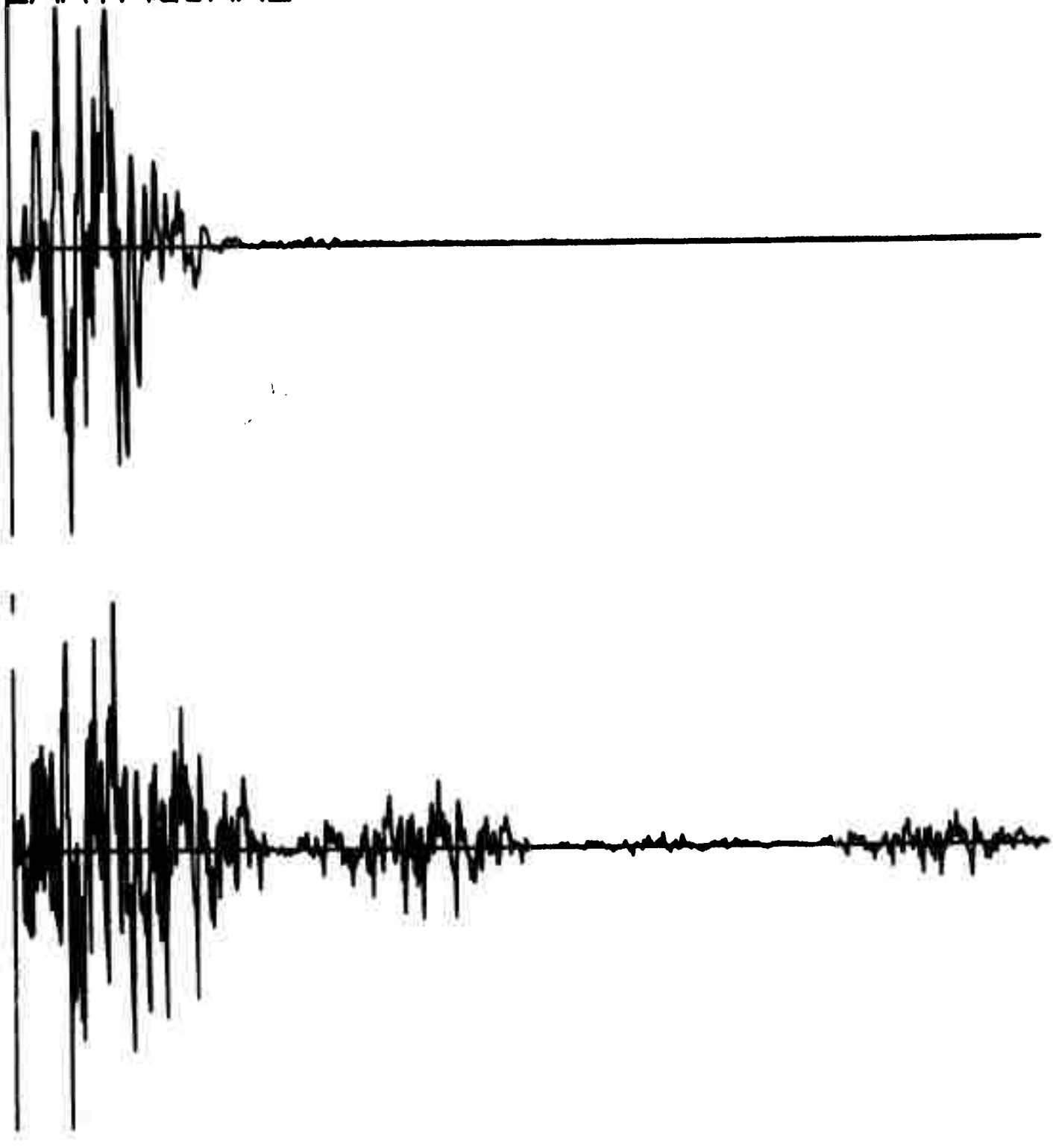
VENT NUMBER 1229
ARTHQUAKE



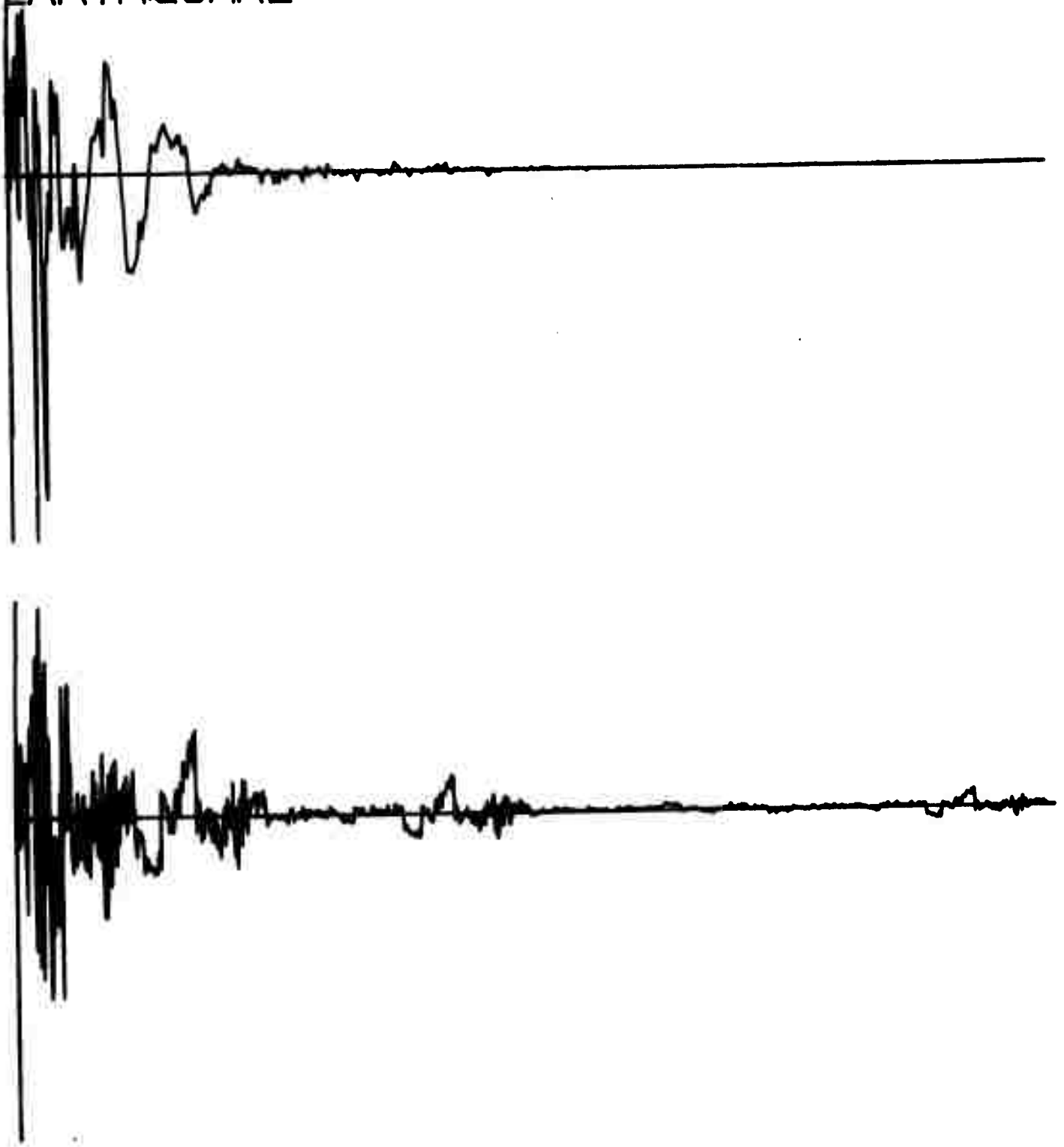
Q214

VENT NUMBER 1230

EARTHQUAKE

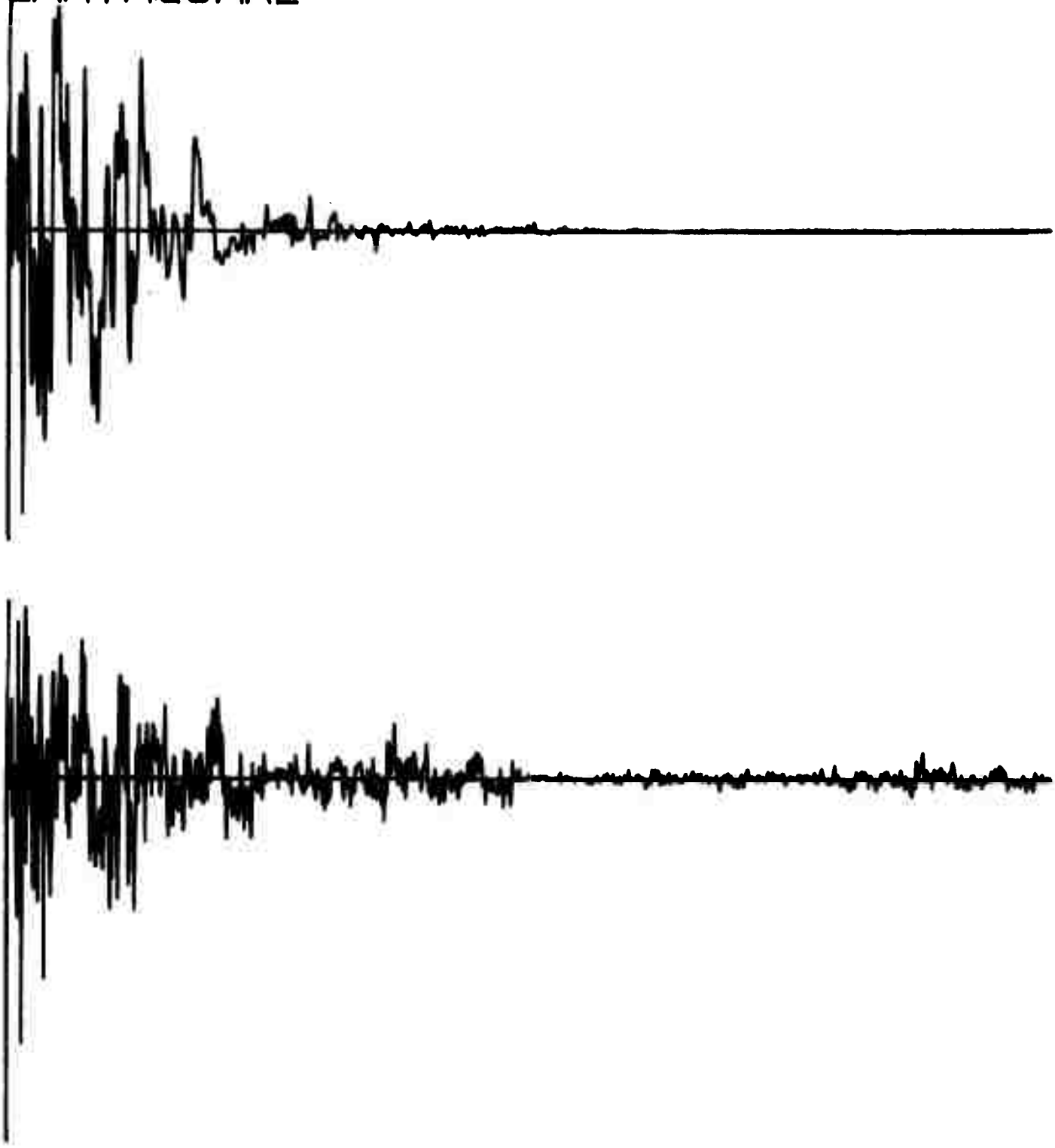


EVENT NUMBER 1231
EARTHQUAKE



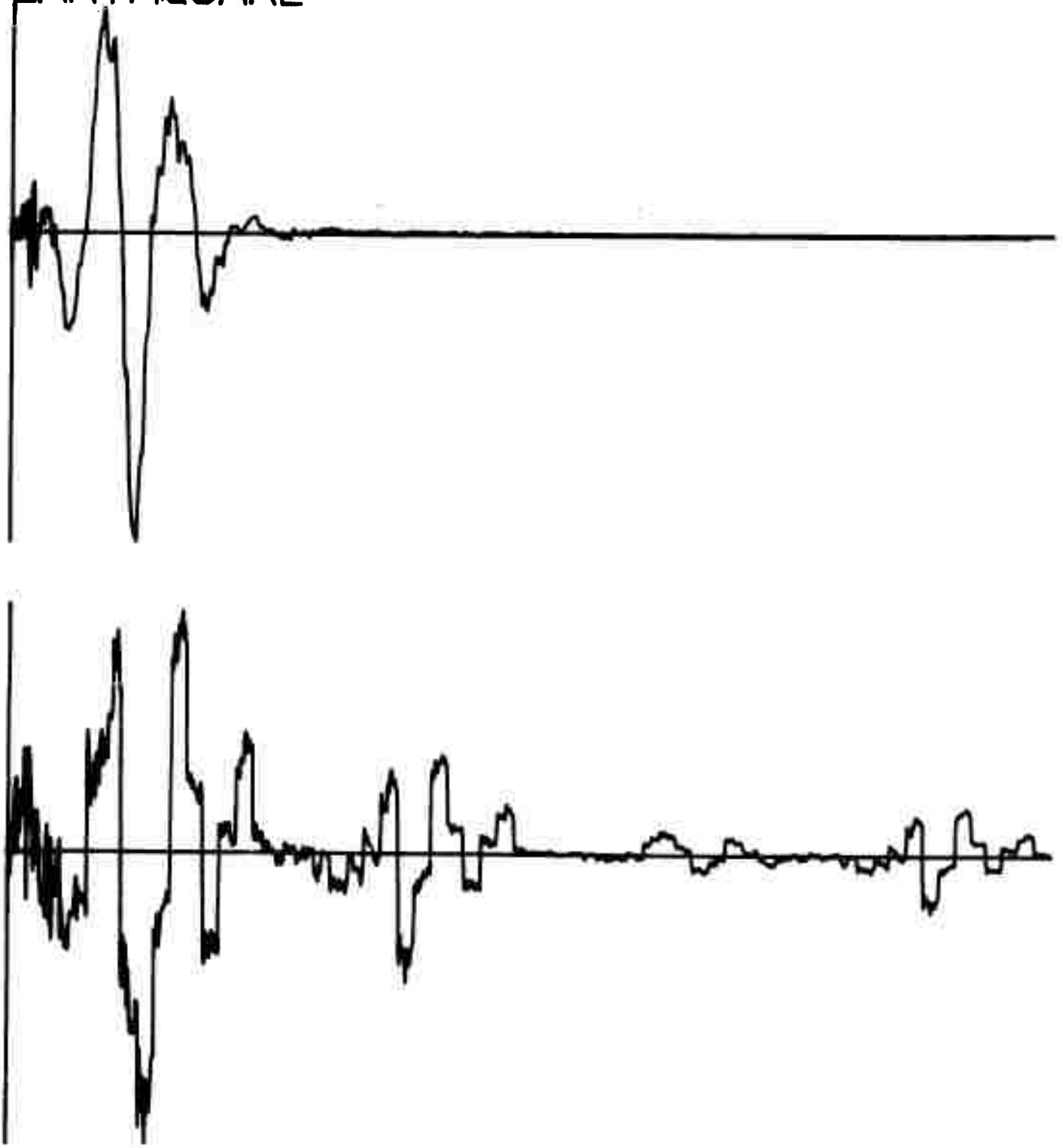
Q218

EVENT NUMBER 1232
EARTHQUAKE

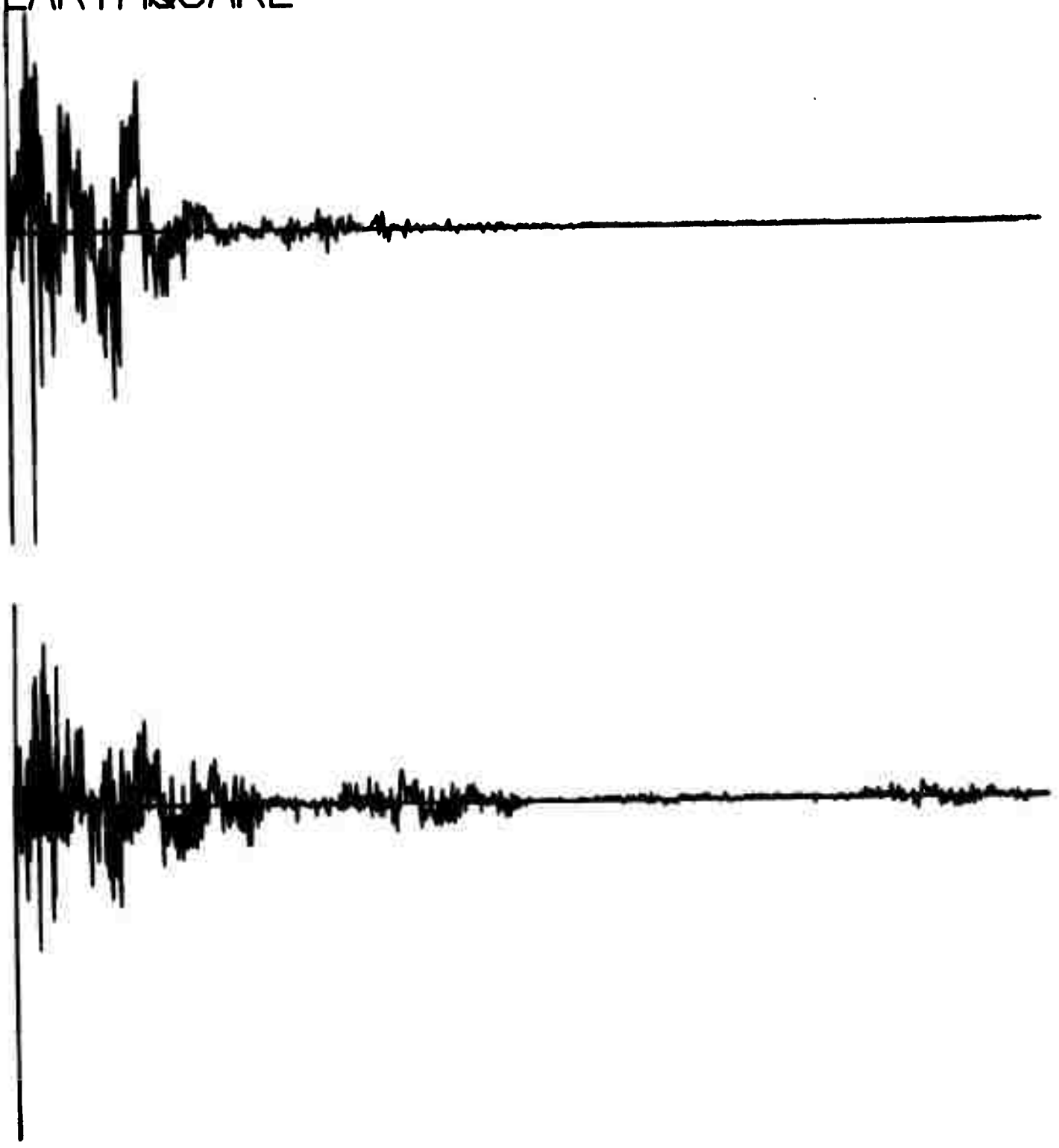


Q220

EVENT NUMBER 1238
EARTHQUAKE

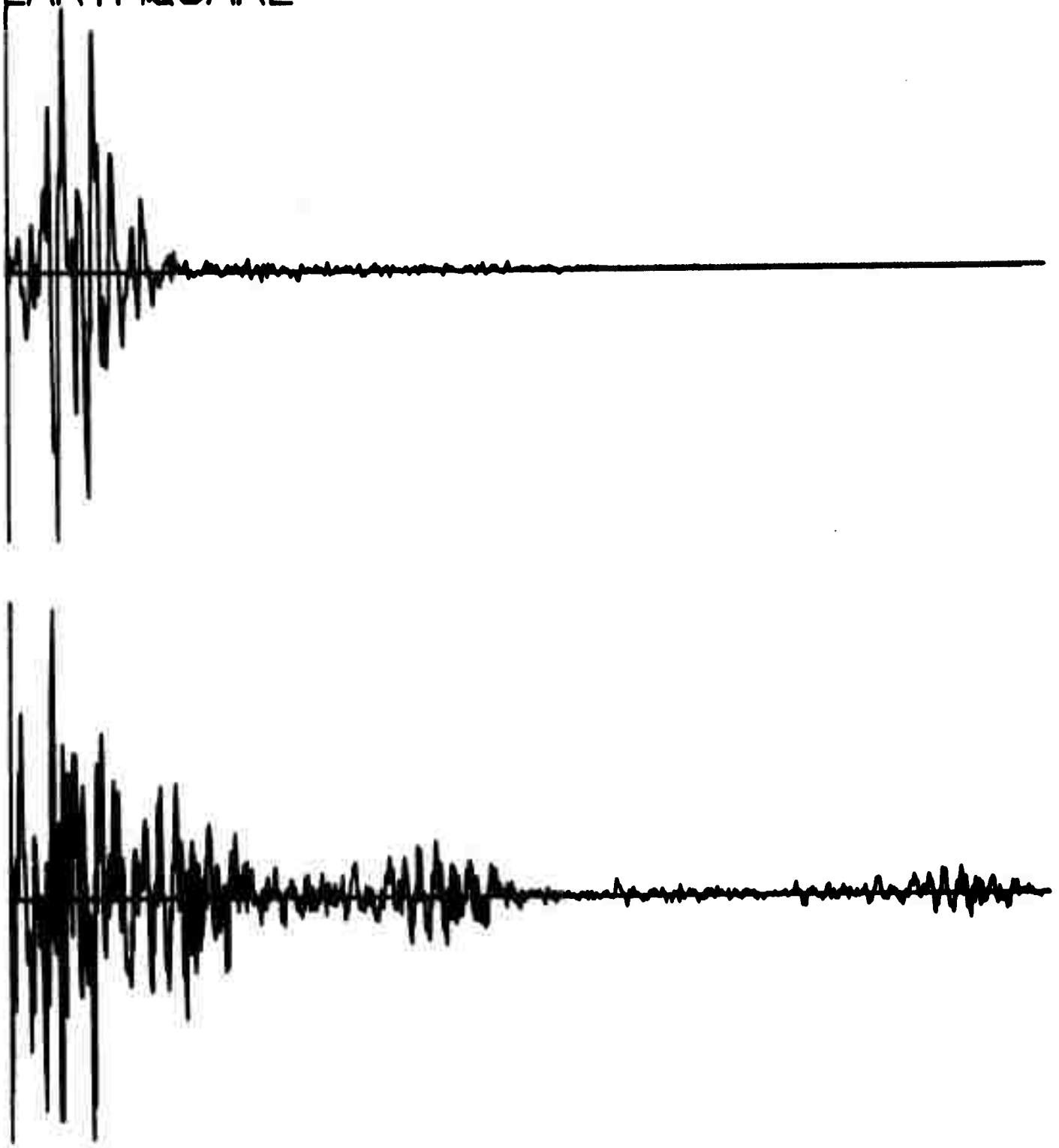


EVENT NUMBER 1239
EARTHQUAKE



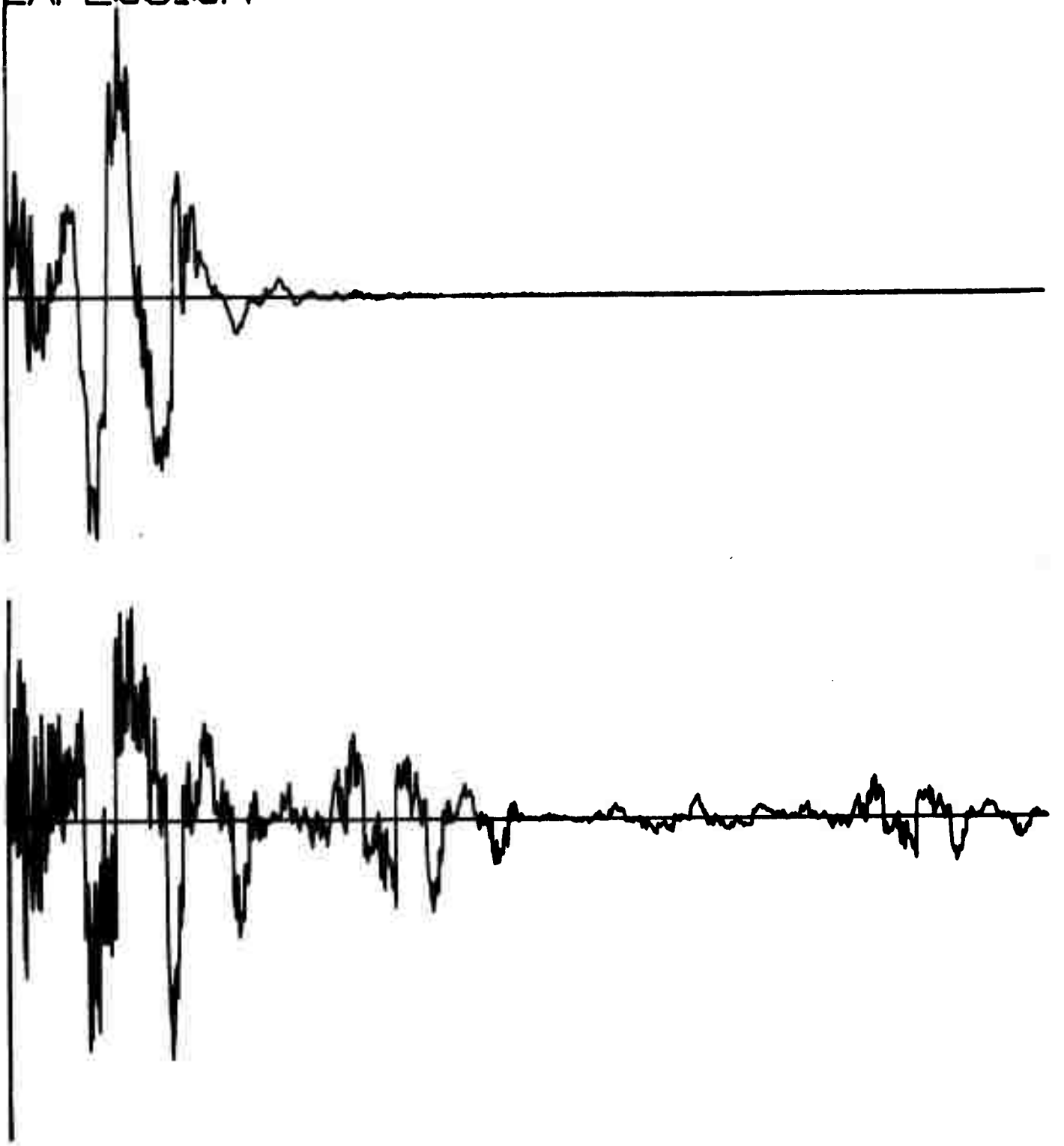
Q224

EVENT NUMBER 1241
EARTHQUAKE



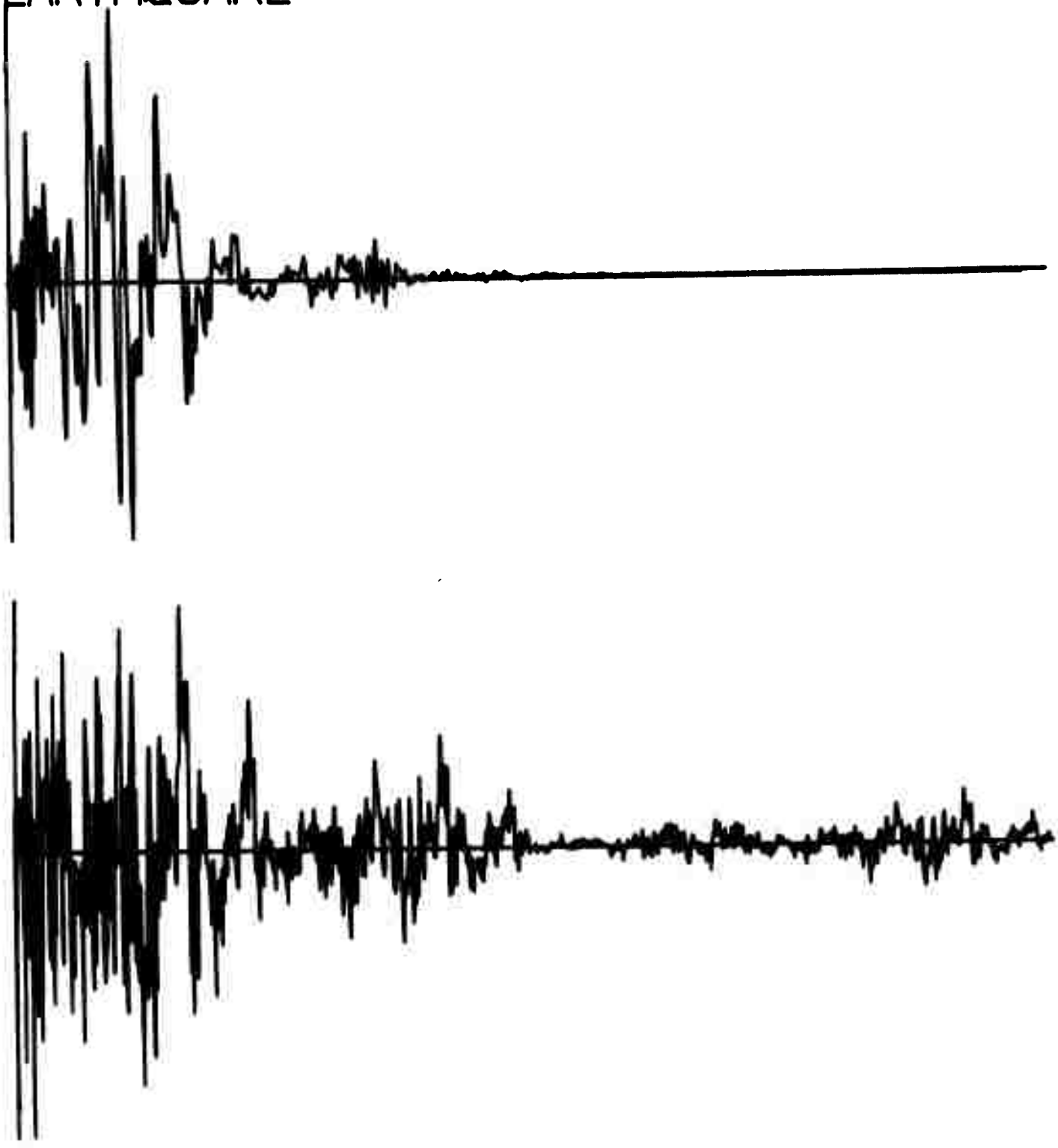
X226

EVENT NUMBER 1533
EXPLOSION



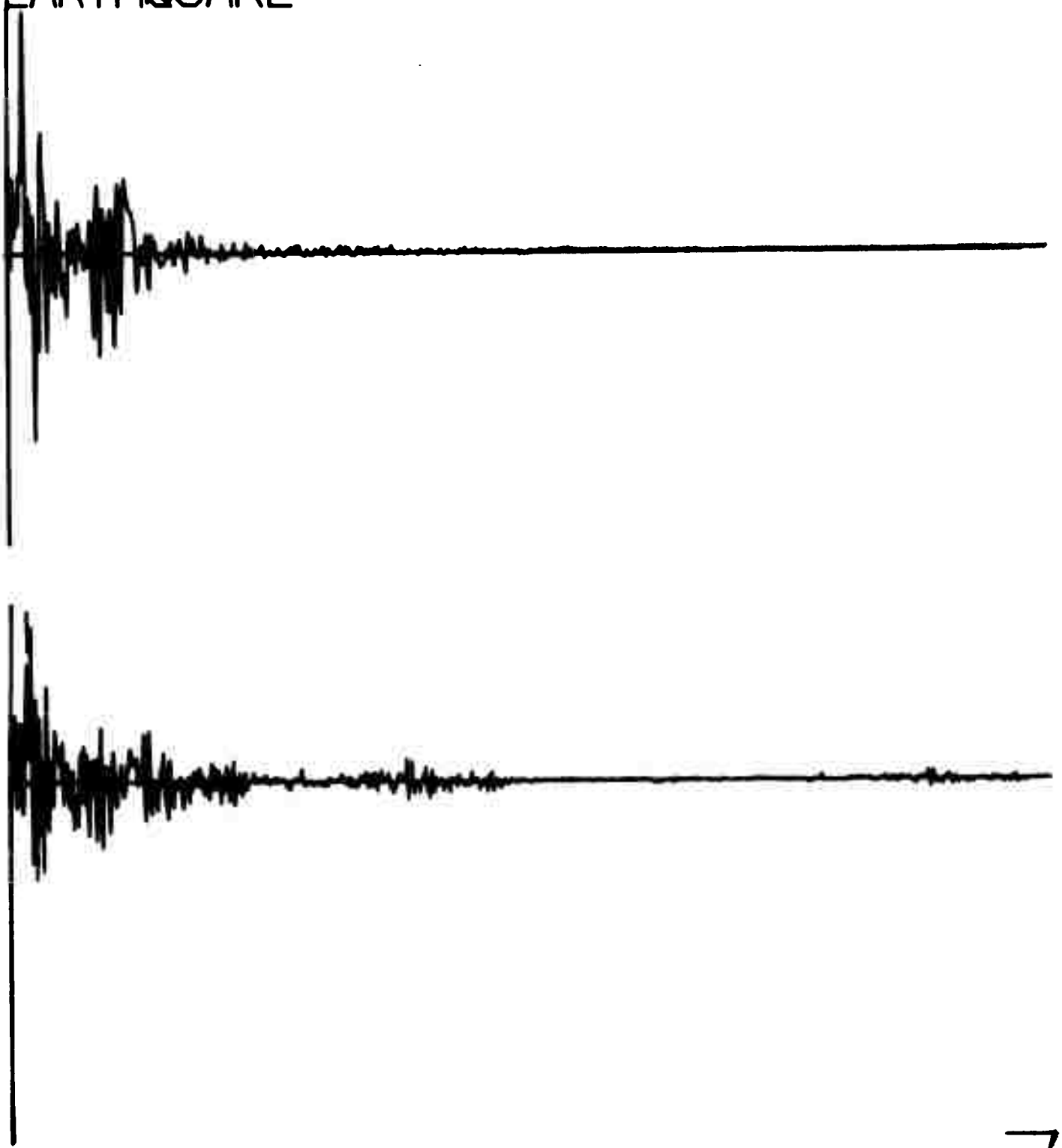
Q228

EVENT NUMBER 1219
EARTHQUAKE



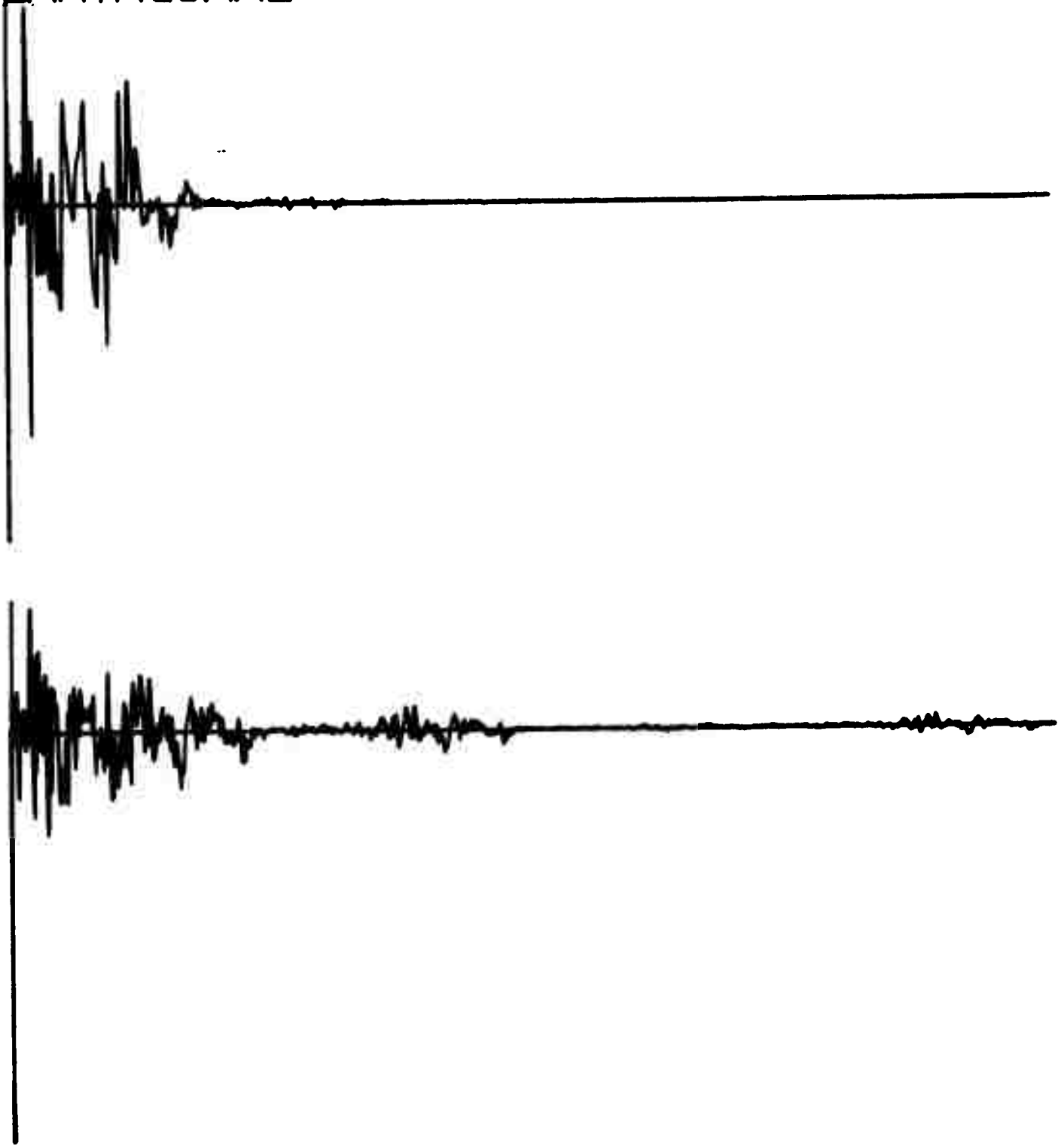
Q230

EVENT NUMBER 1245
EARTHQUAKE



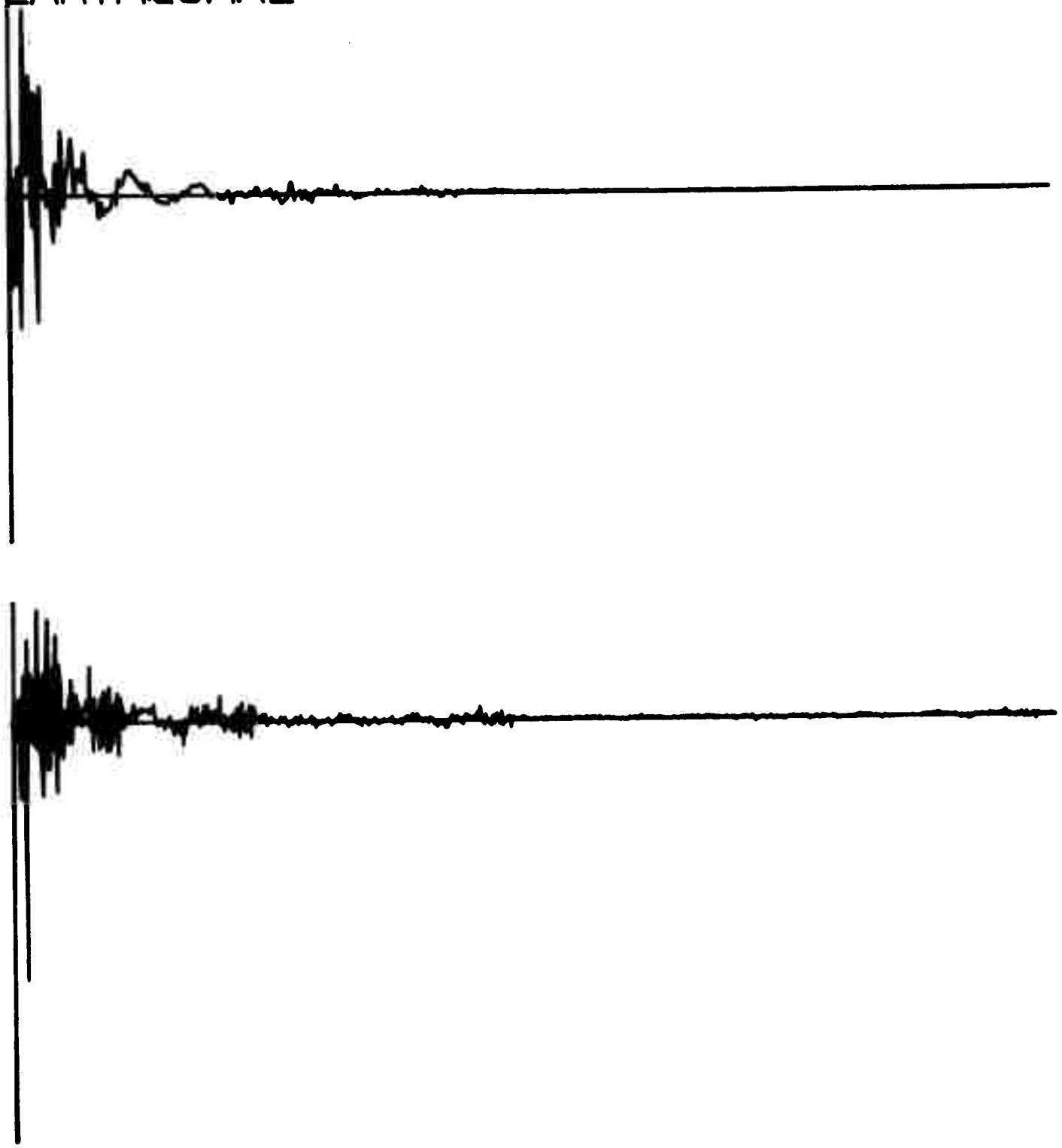
Q232

EVENT NUMBER 1247
EARTHQUAKE



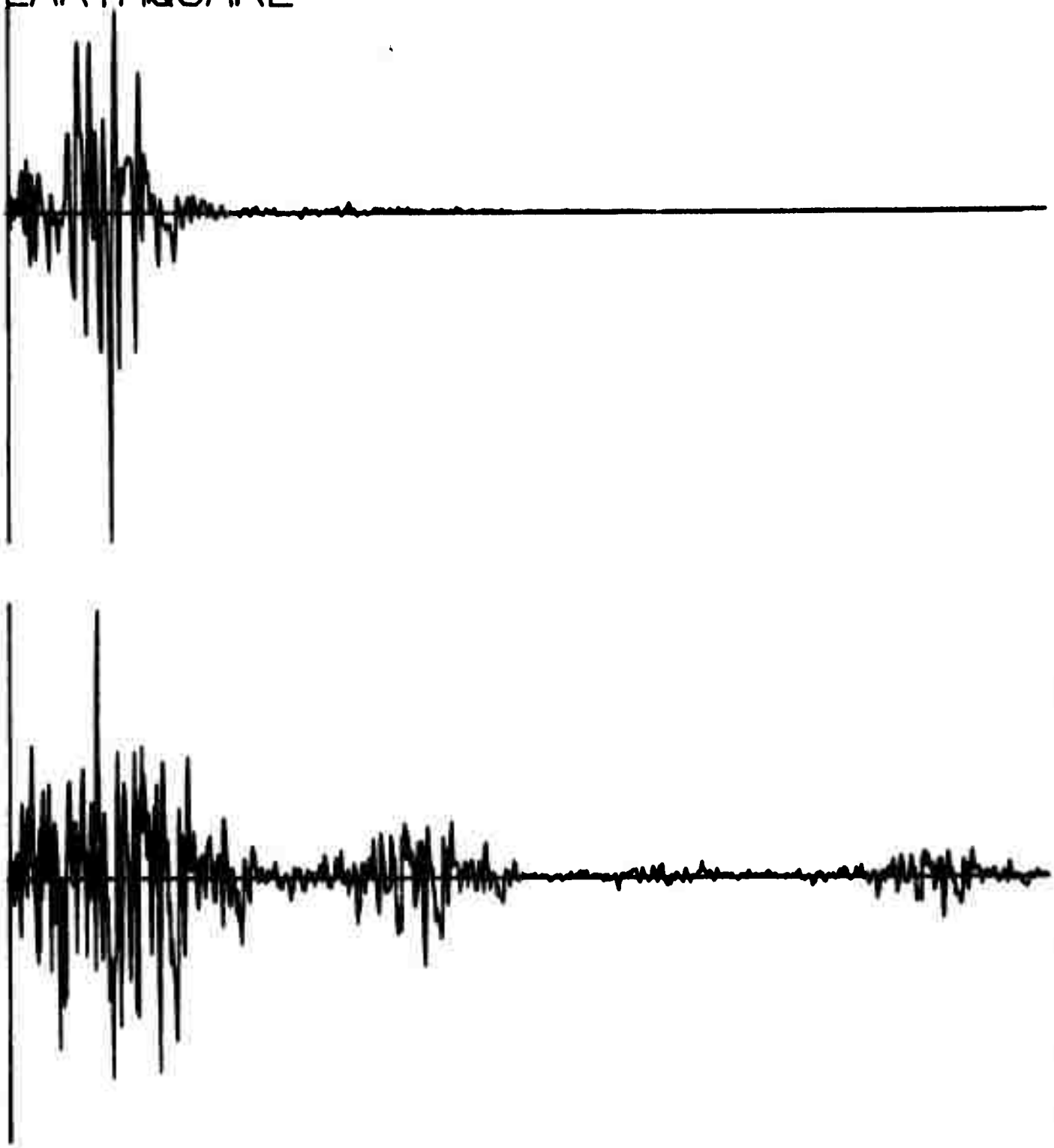
Q234

EVENT NUMBER 1248
EARTHQUAKE



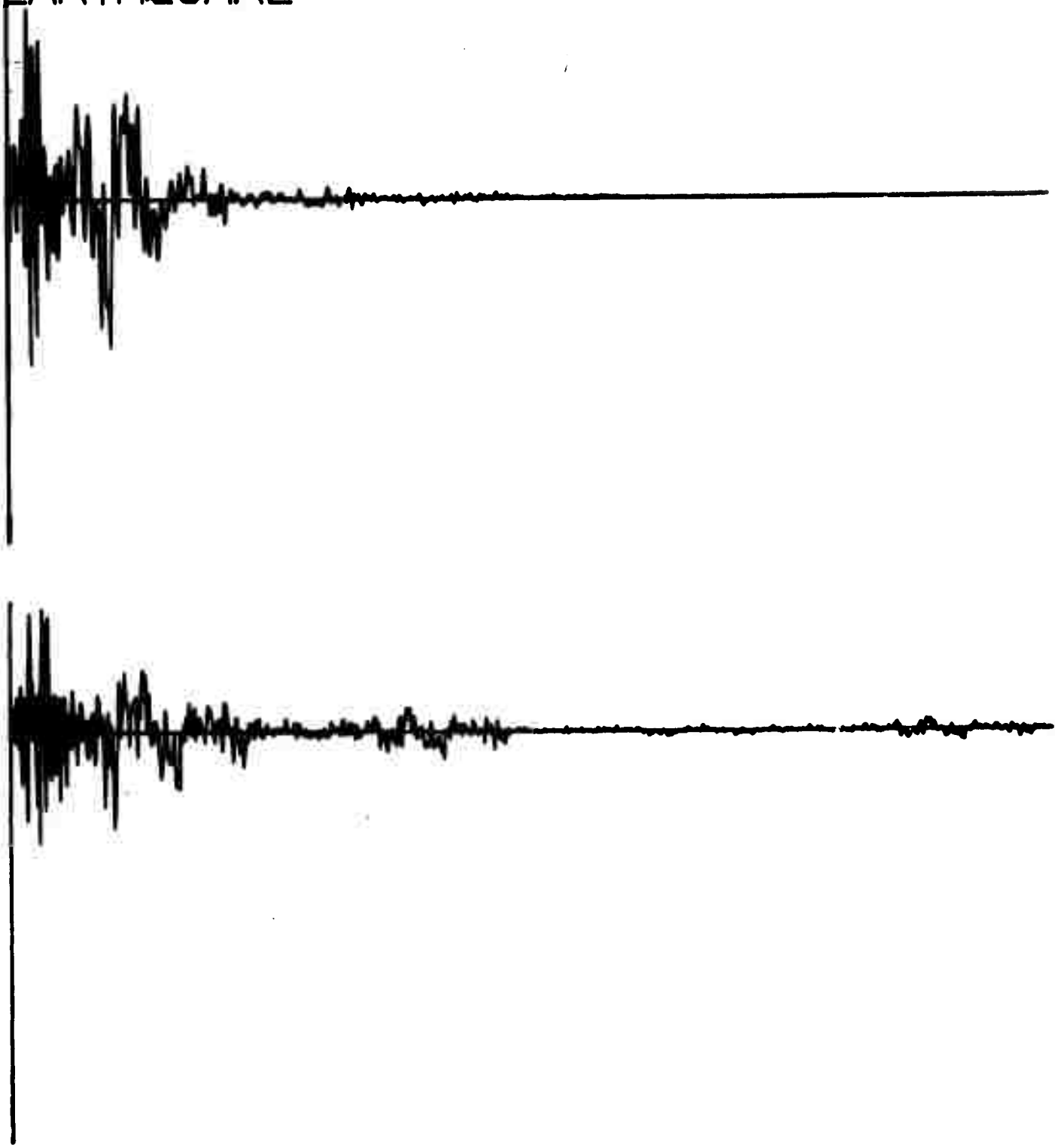
Q236

EVENT NUMBER 1249
EARTHQUAKE



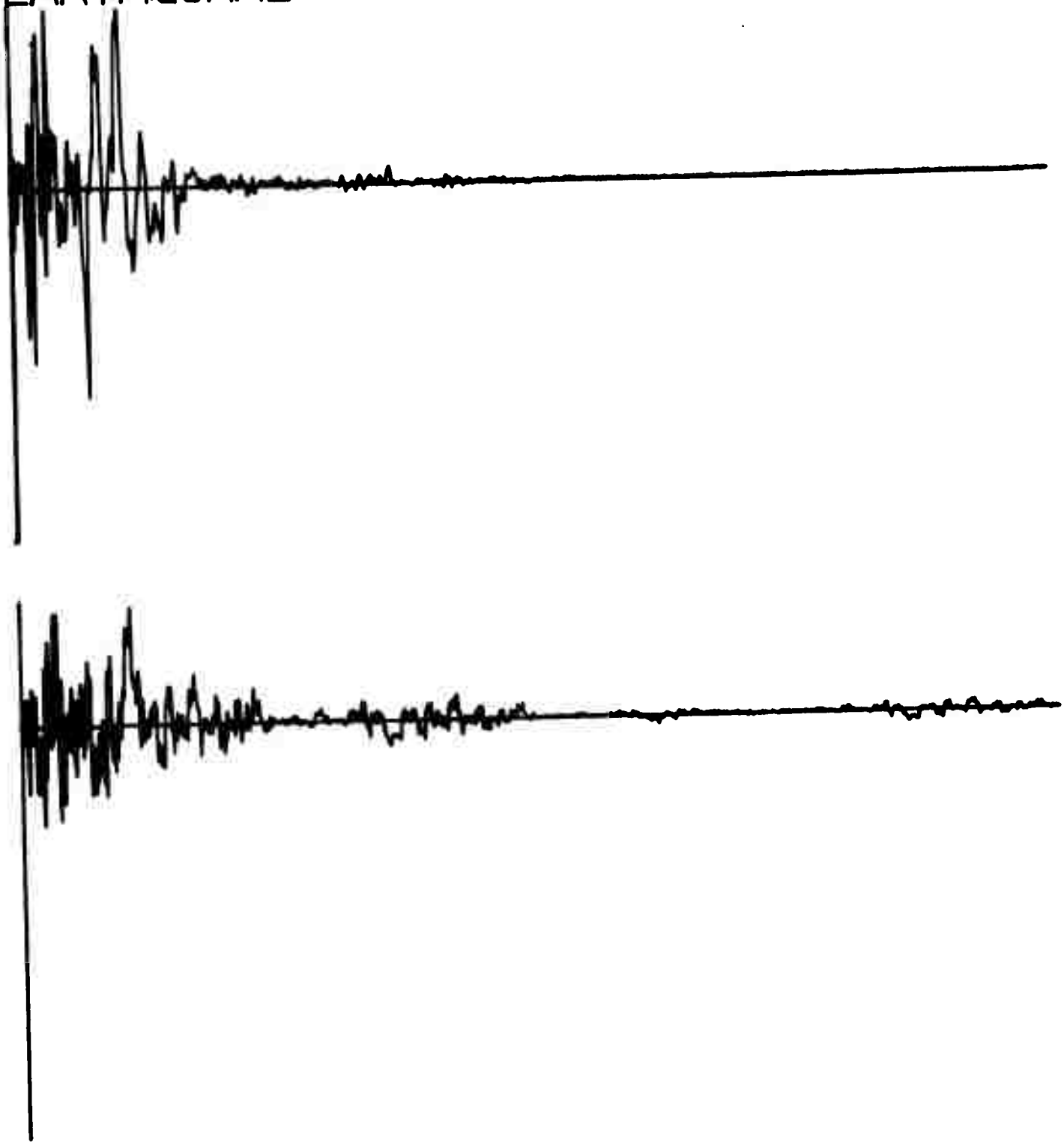
Q238

EVENT NUMBER 1251
EARTHQUAKE



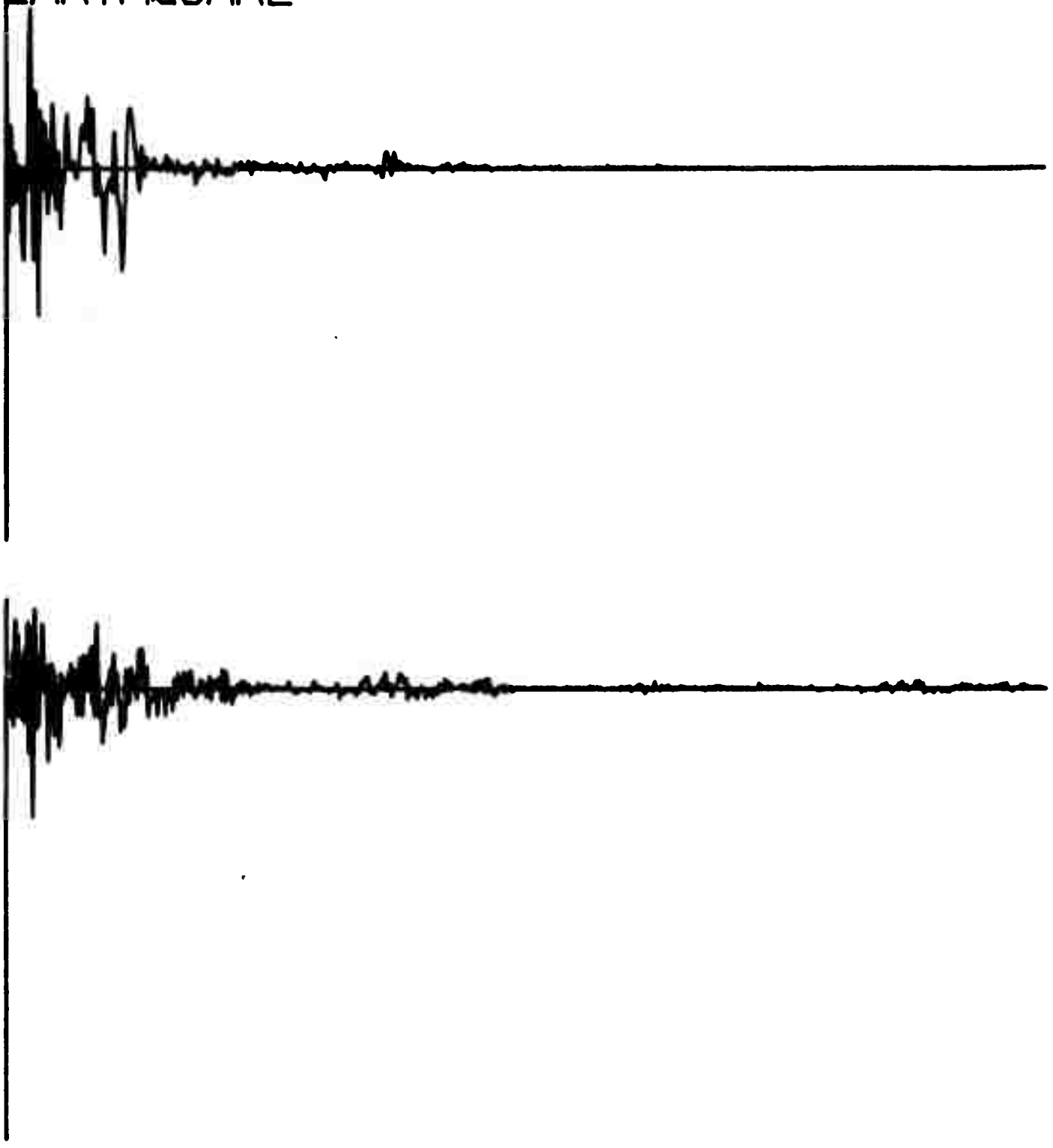
Q240

EVENT NUMBER 1253
EARTHQUAKE



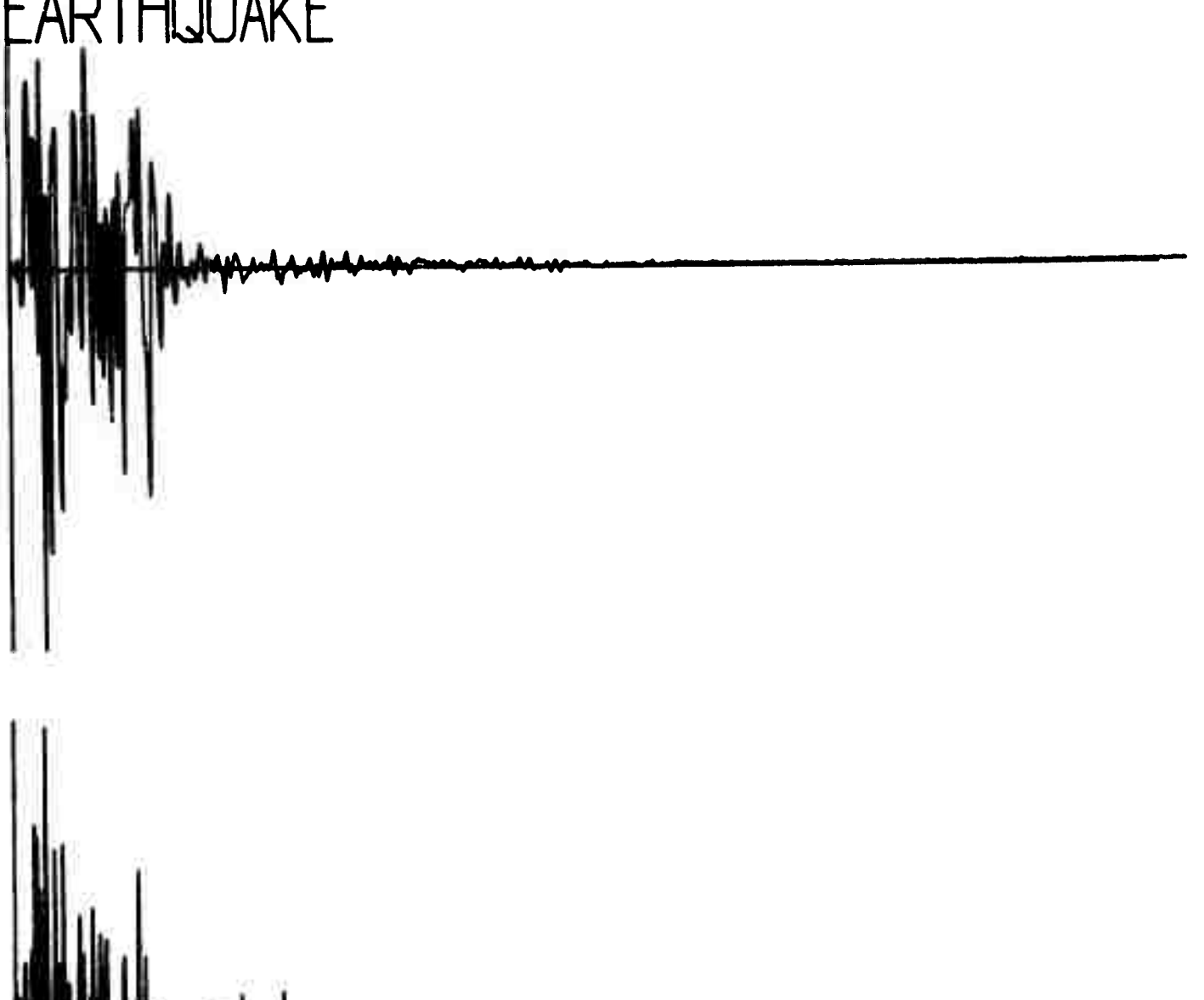
Q242

EVENT NUMBER 1254
EARTHQUAKE

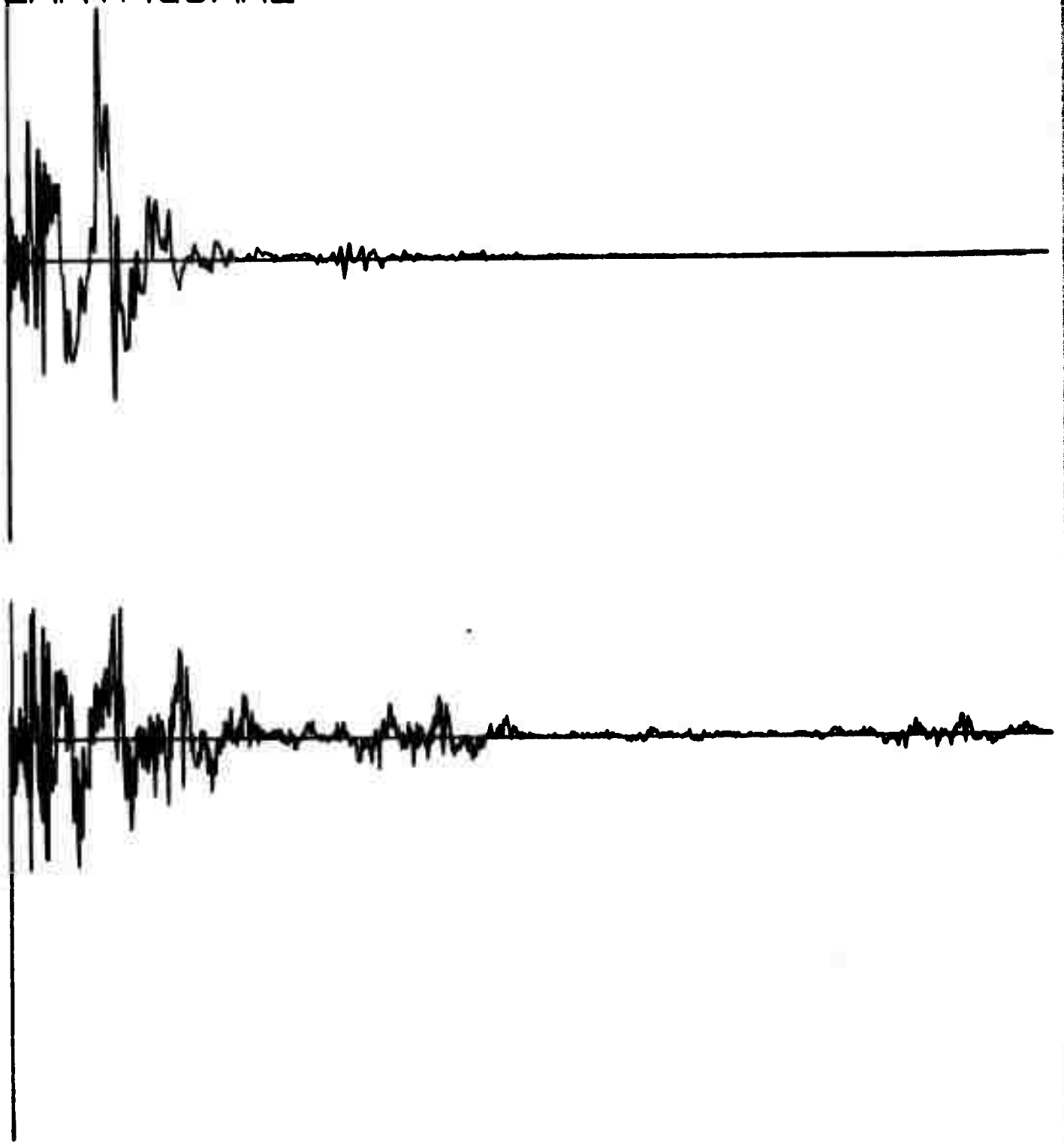


Q244

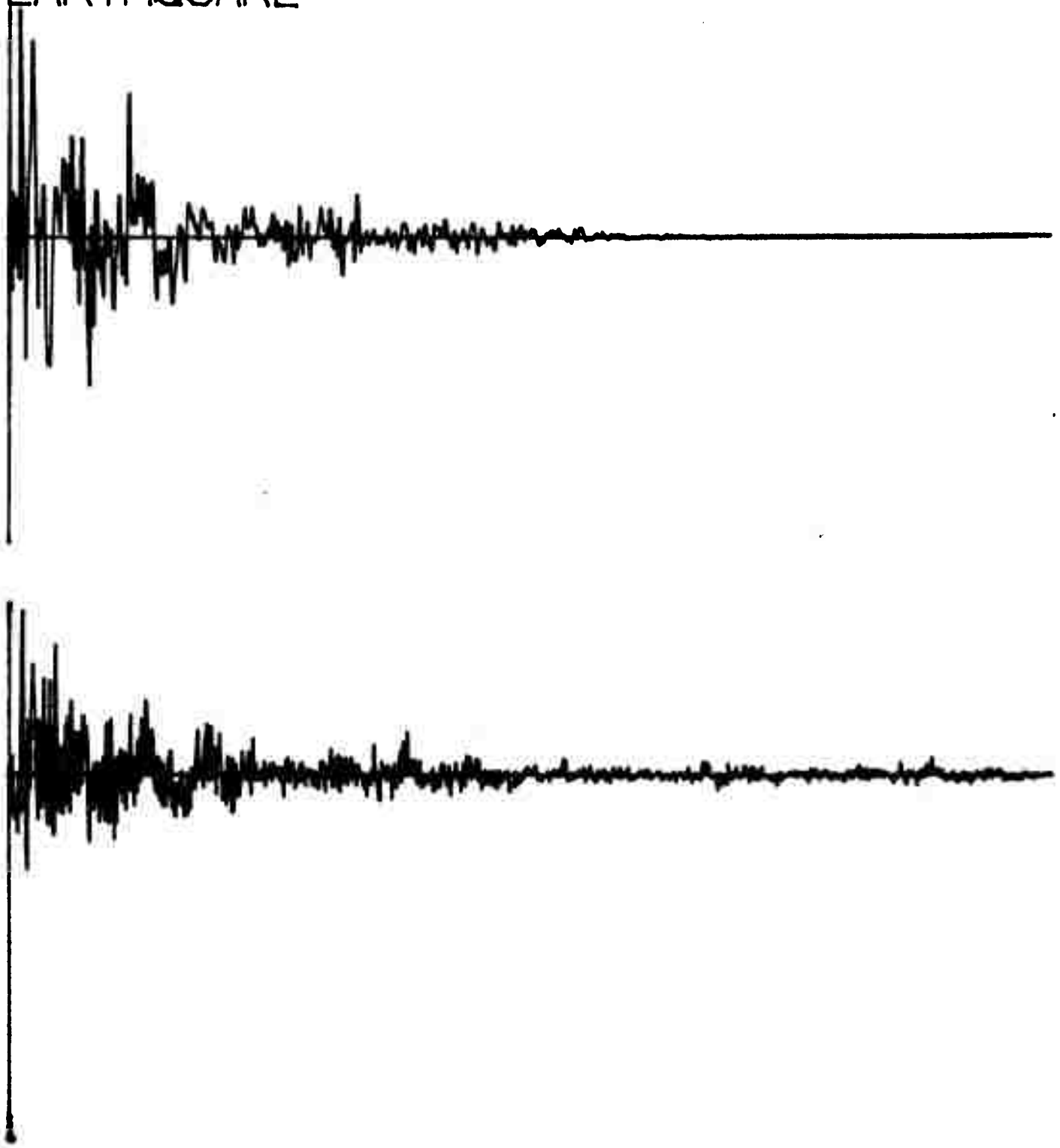
EVENT NUMBER 1256
EARTHQUAKE



EVENT NUMBER 1267
EARTHQUAKE

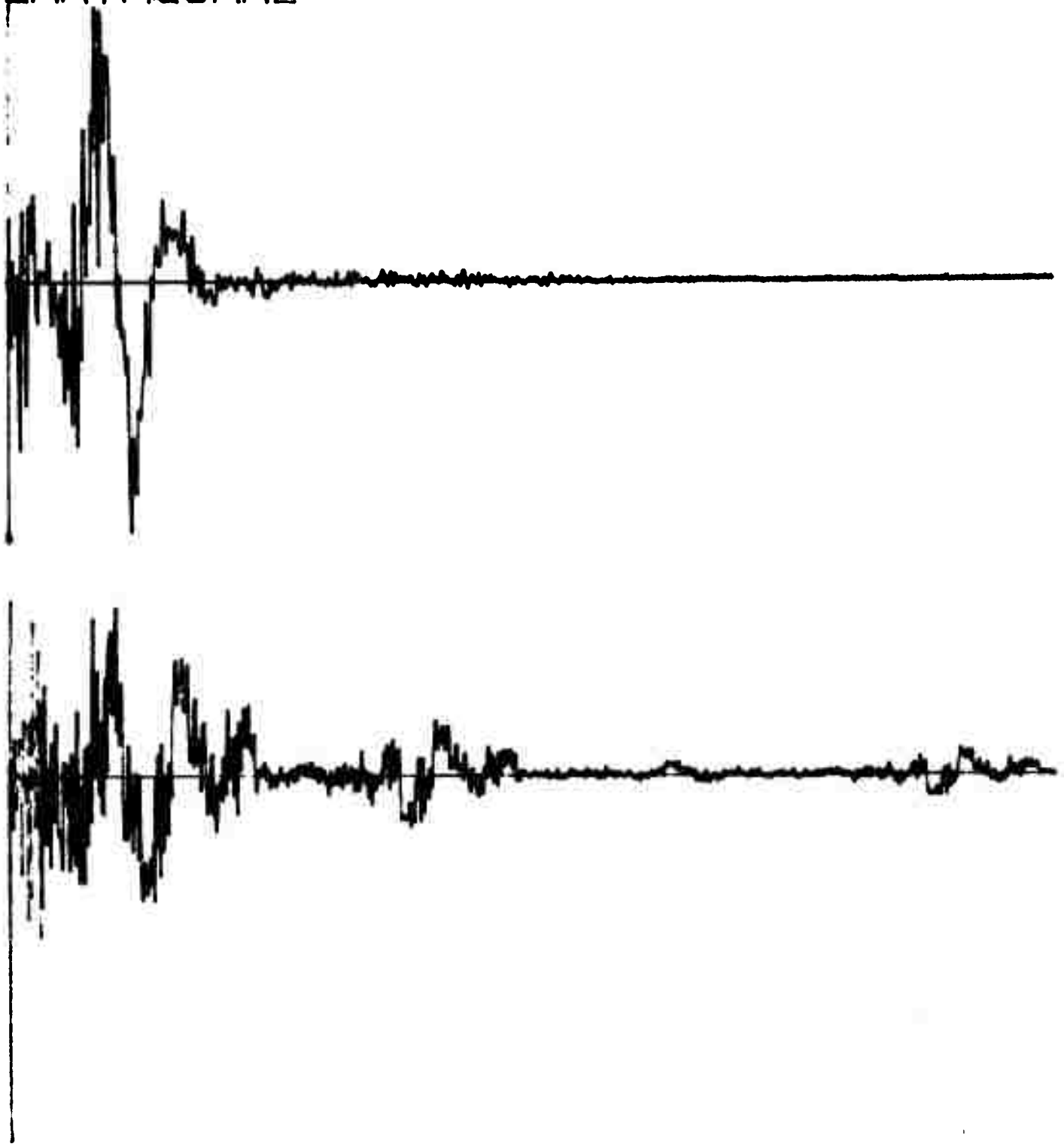


EVENT NUMBER 1258
EARTHQUAKE



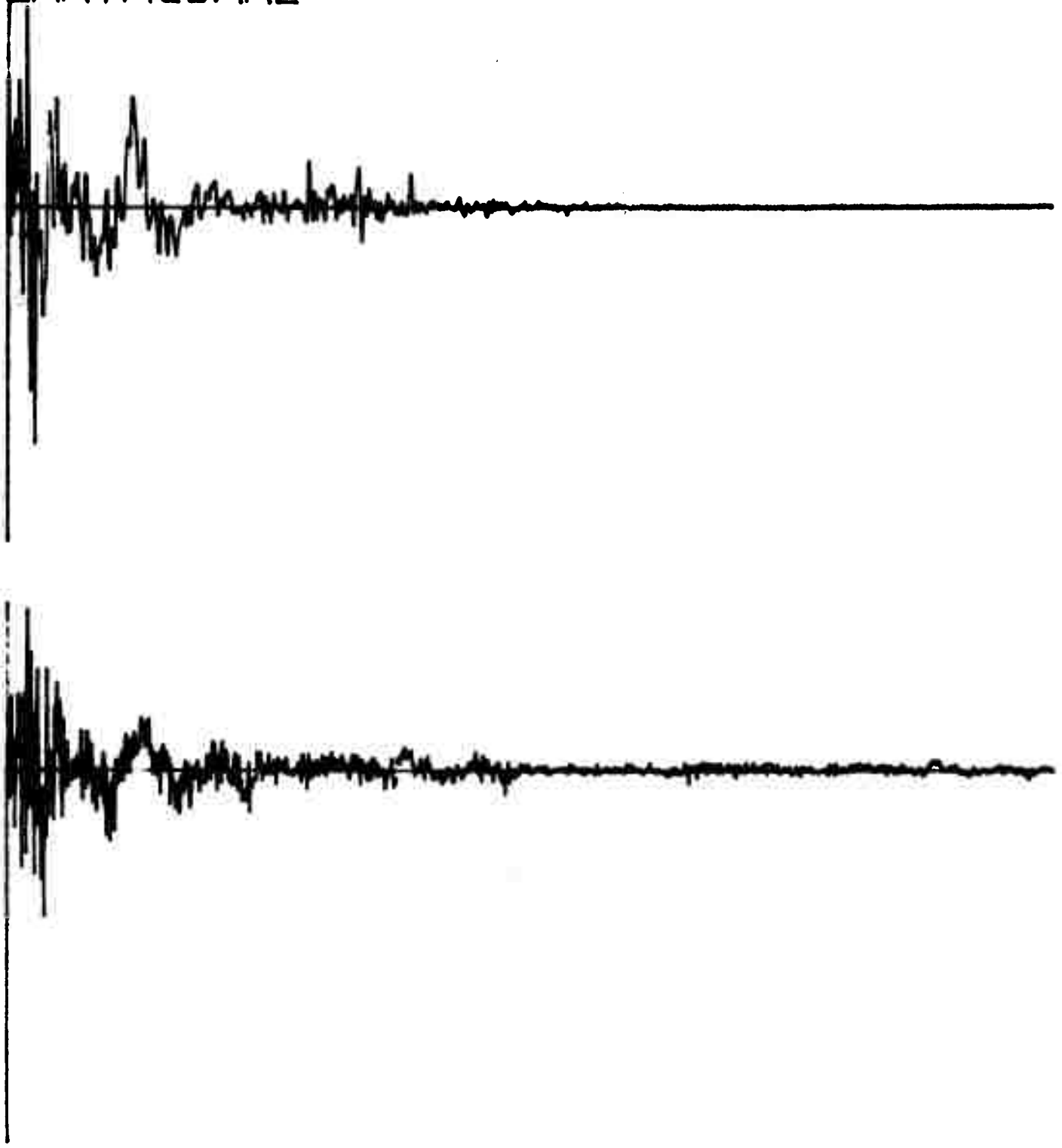
Q250

EVENT NUMBER 1259
EARTHQUAKE



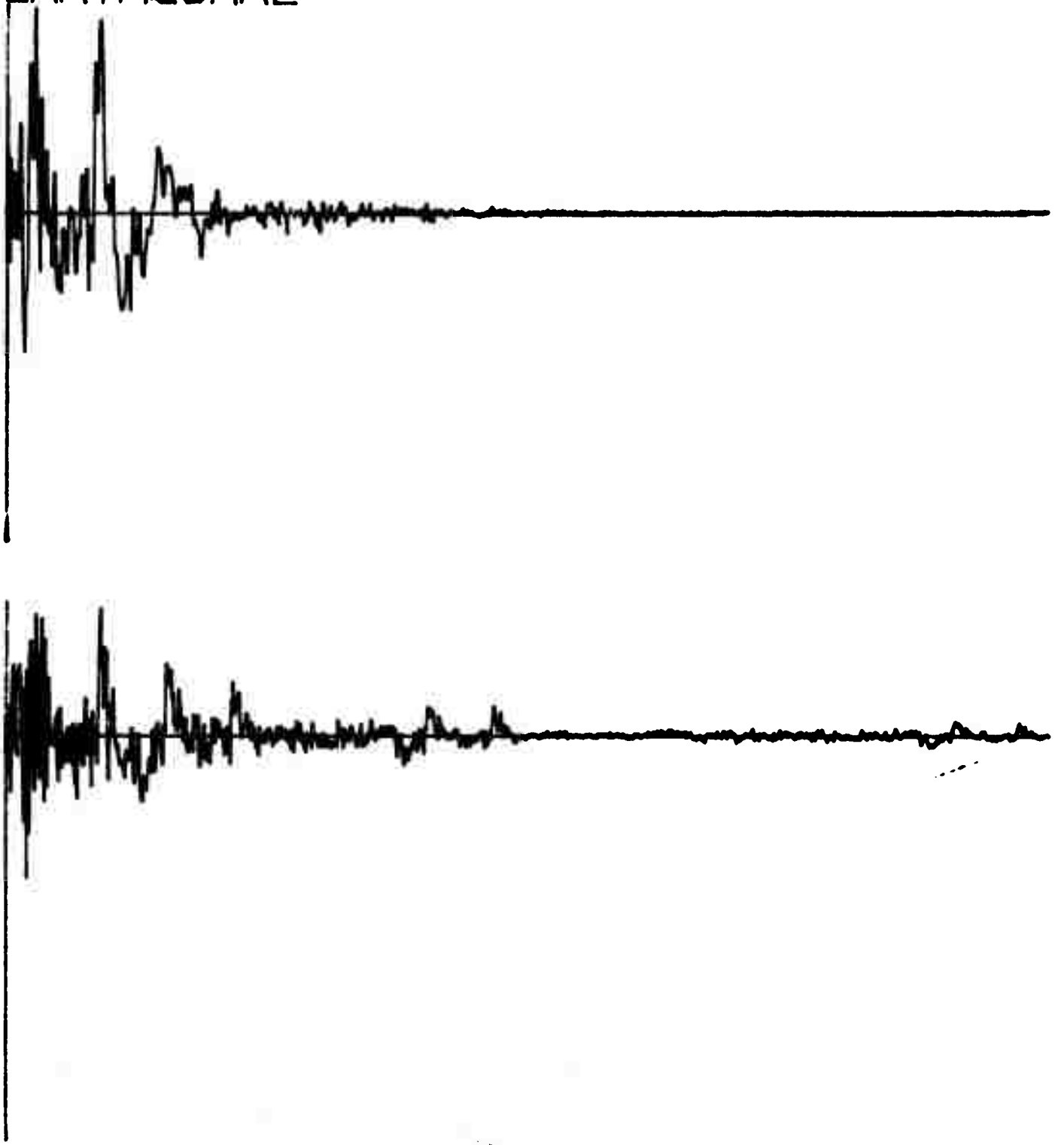
Q252

EVENT NUMBER 1260
EARTHQUAKE



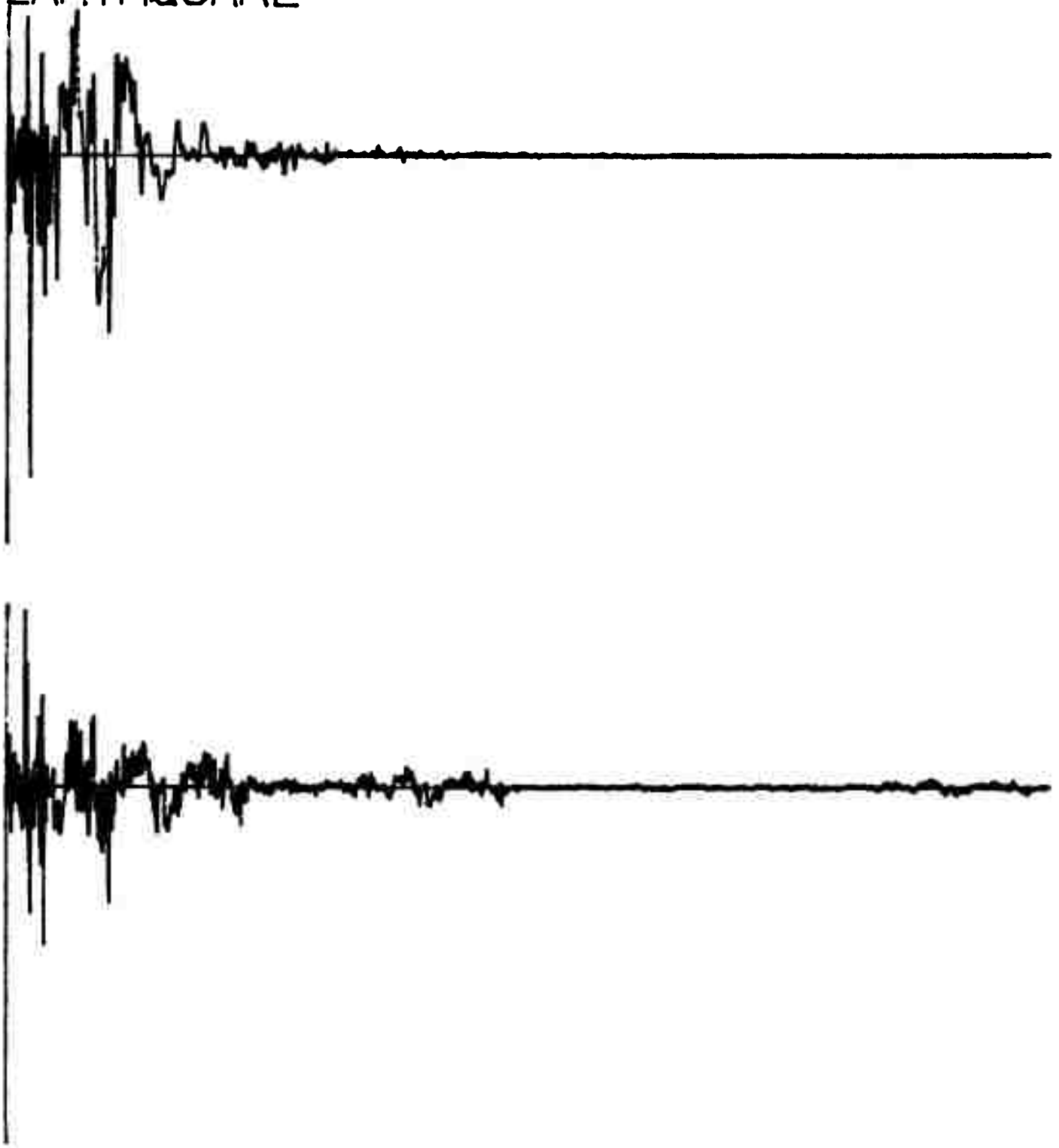
Q254

EVENT NUMBER 1261
EARTHQUAKE



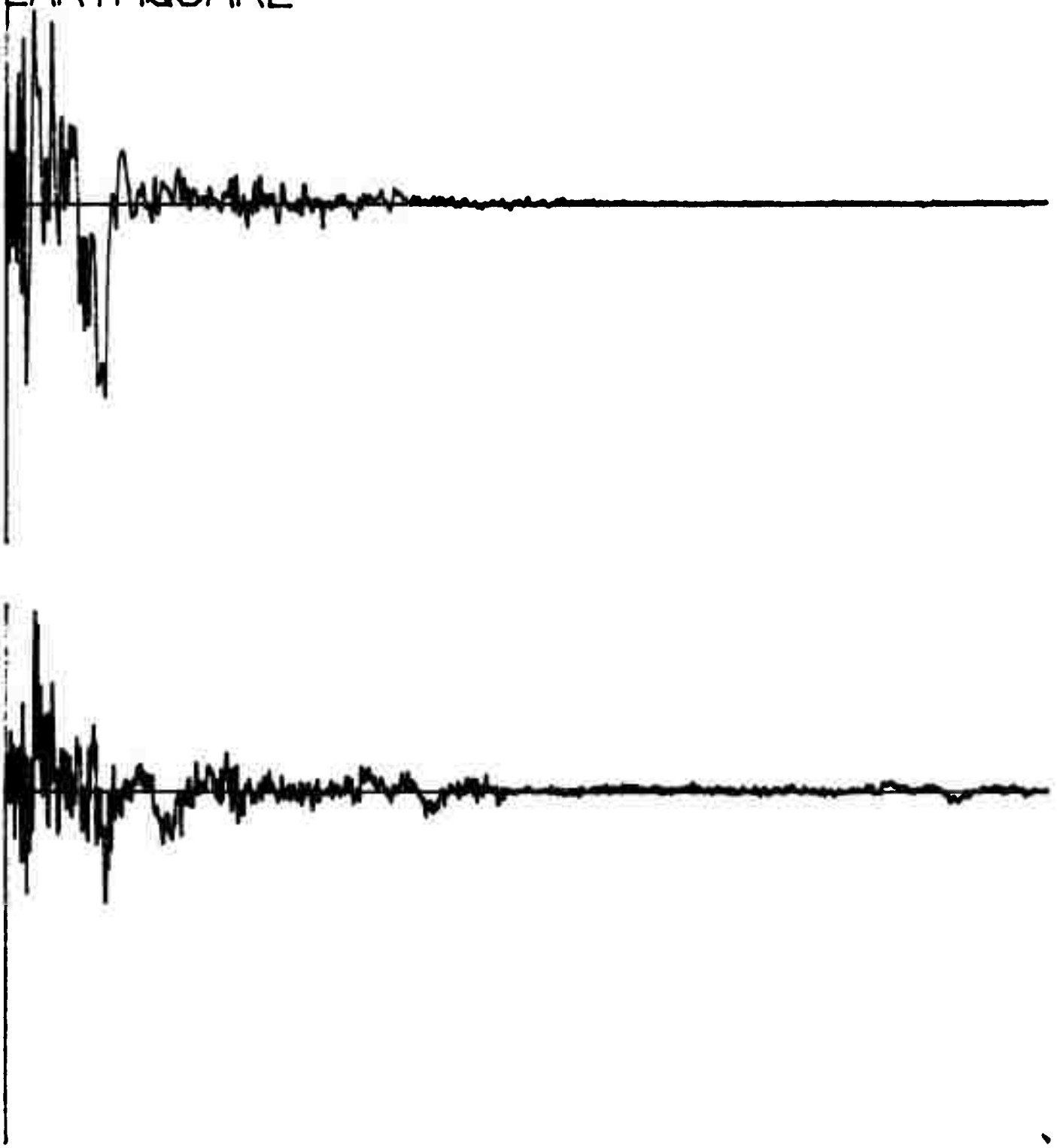
Q256

EVENT NUMBER 1262
EARTHQUAKE



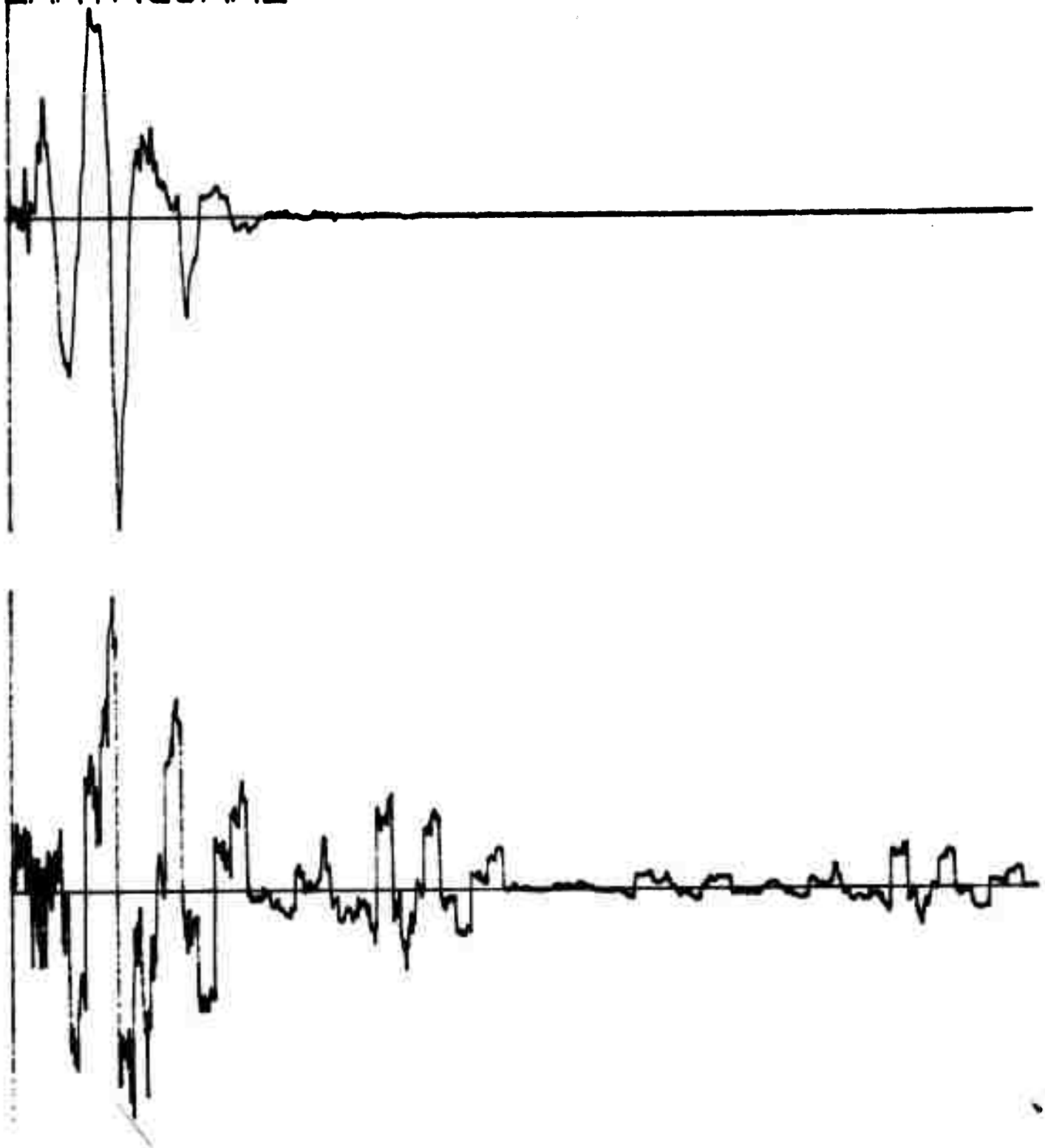
Q258

EVENT NUMBER 1264
EARTHQUAKE



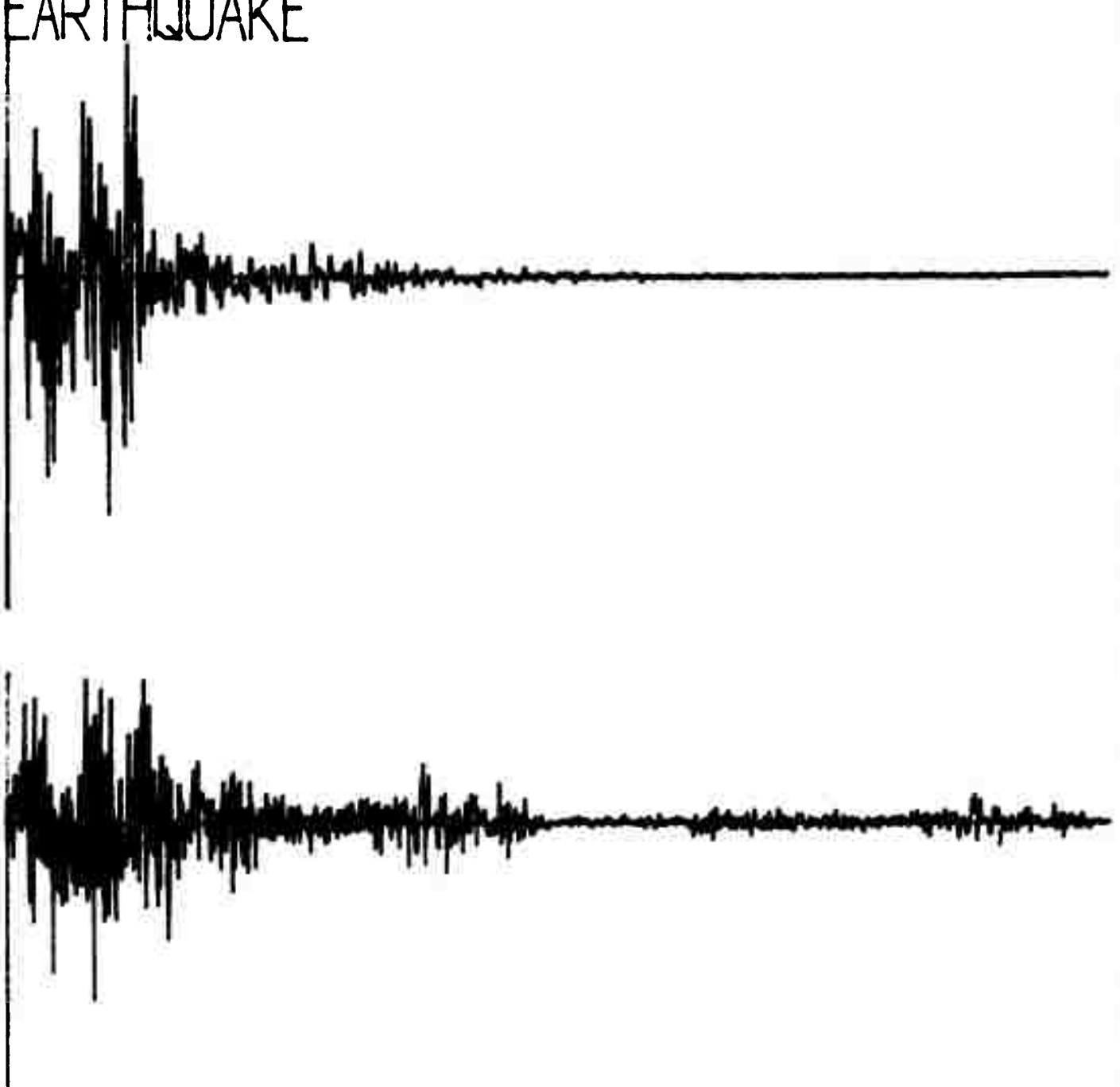
Q260

EVENT NUMBER 1263
EARTHQUAKE

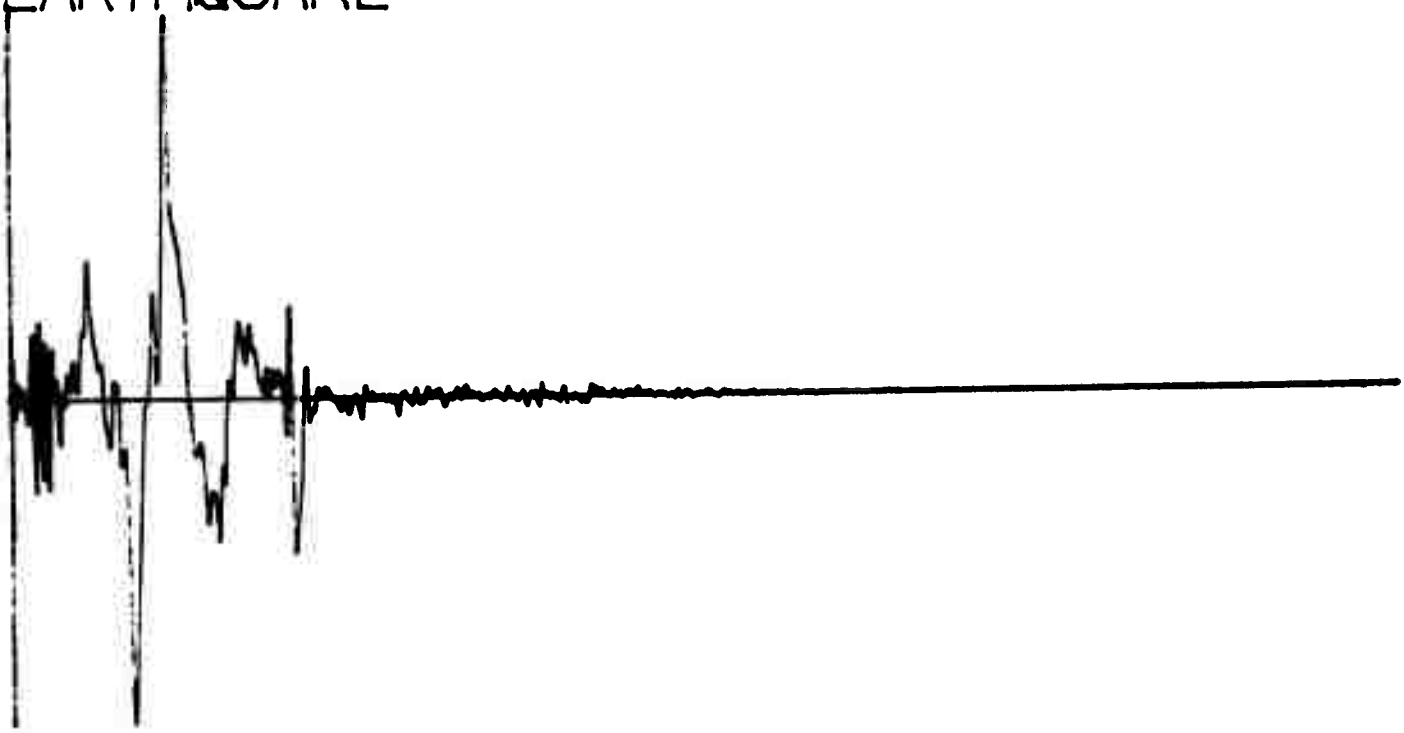


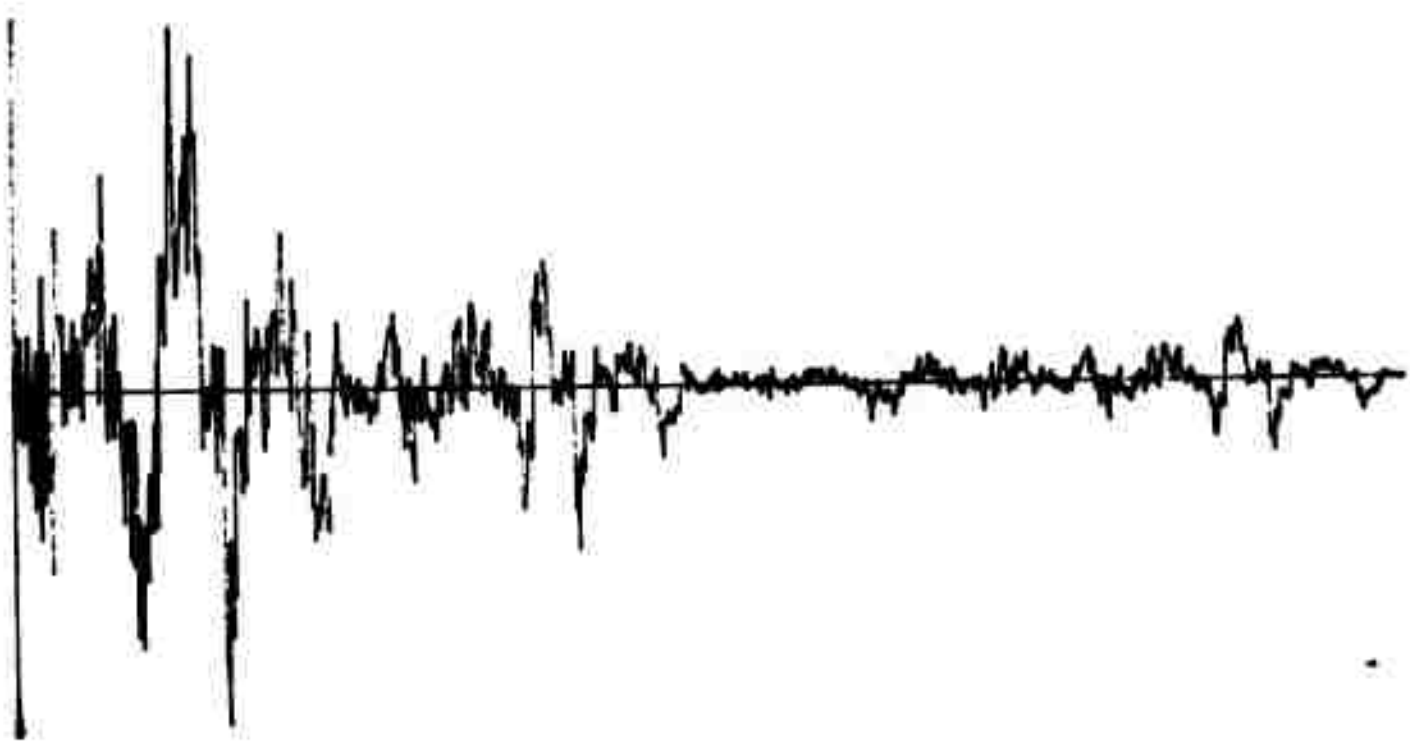
Q262

VENT NUMBER 1269
EARTHQUAKE



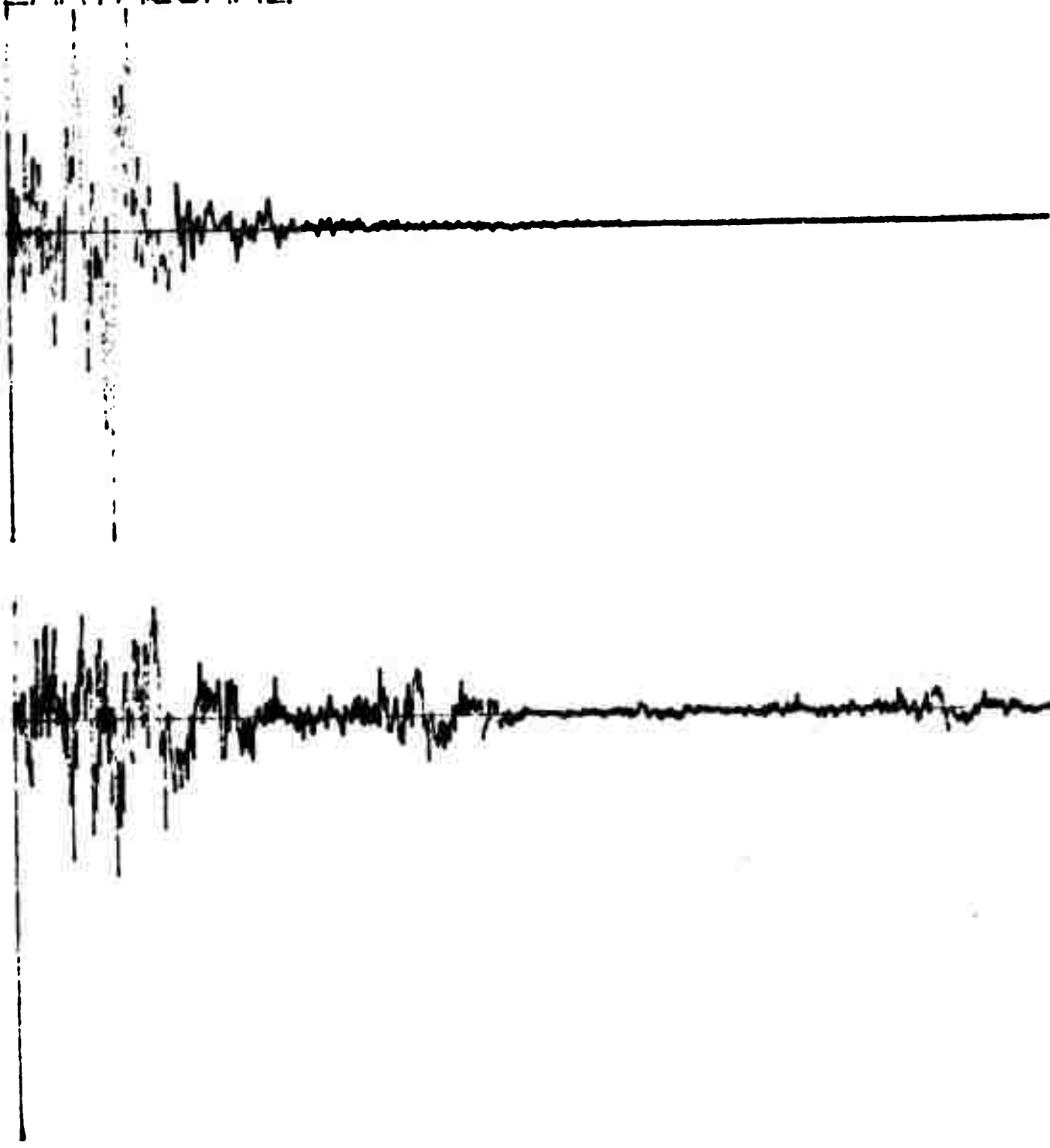
EVENT NUMBER 1268
EARTHQUAKE





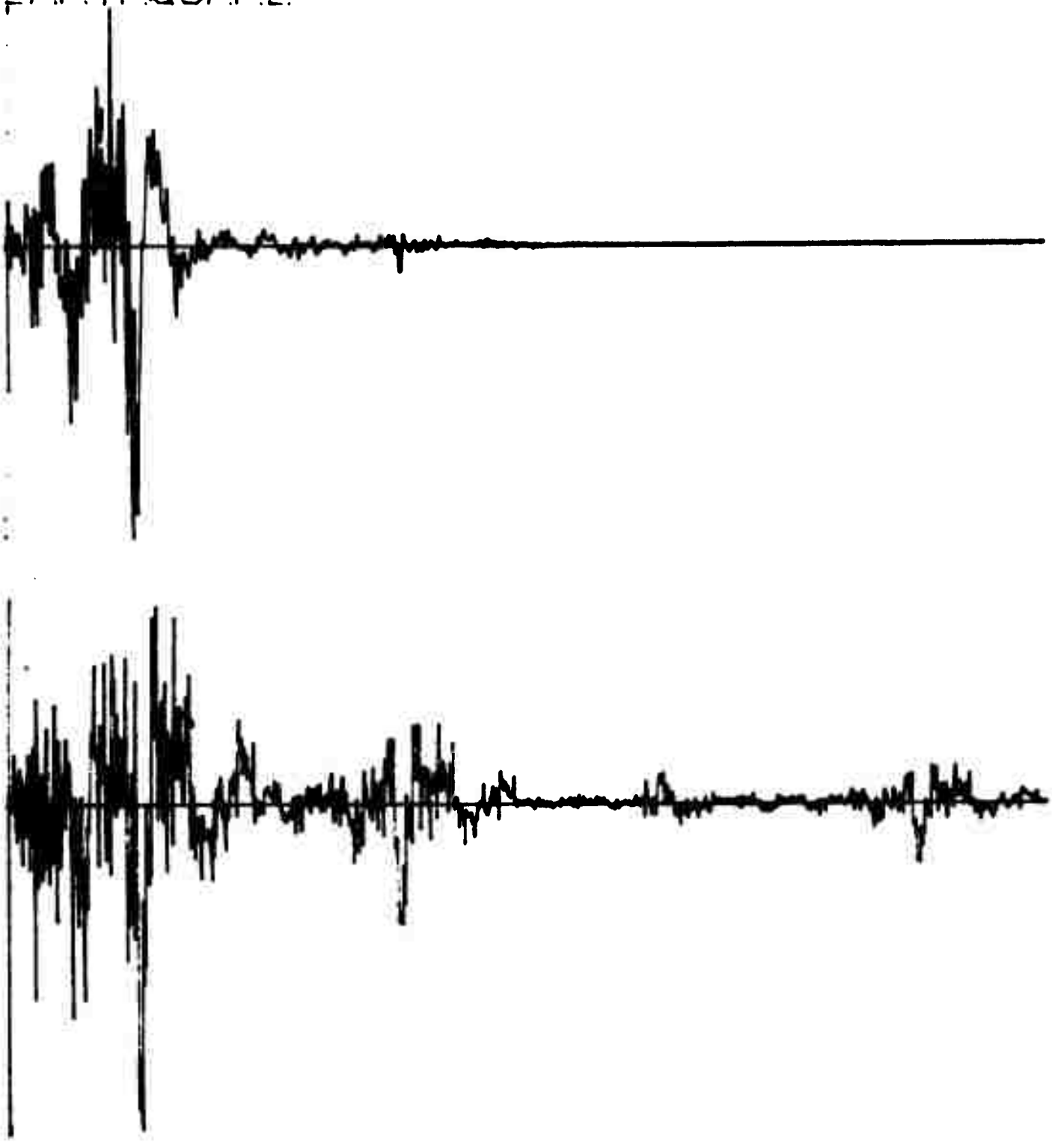
Q266

EVENT NUMBER 1270
EARTHQUAKE



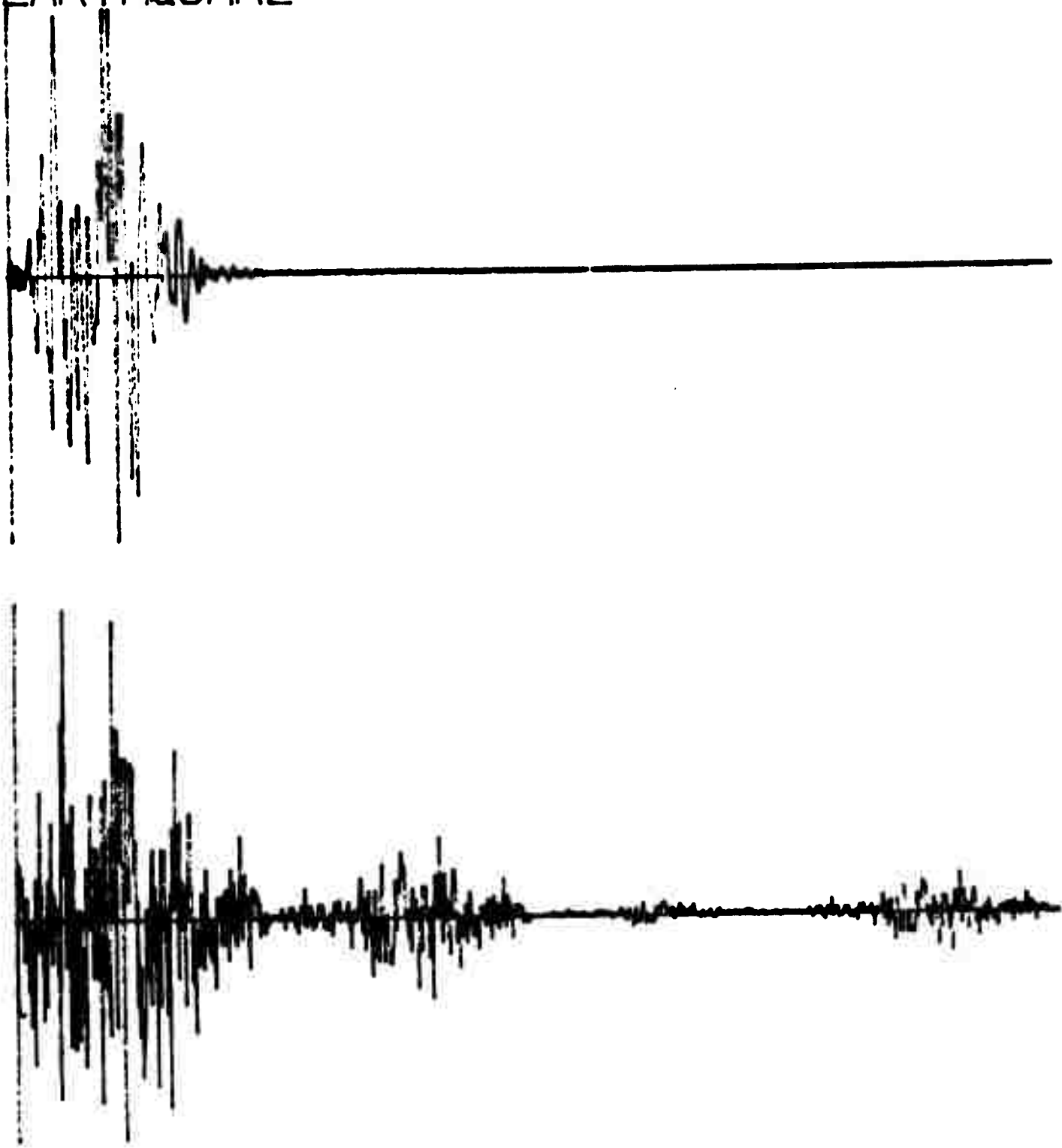
Q268

EVENT NUMBER 127
EARTHQUAKE



Q270

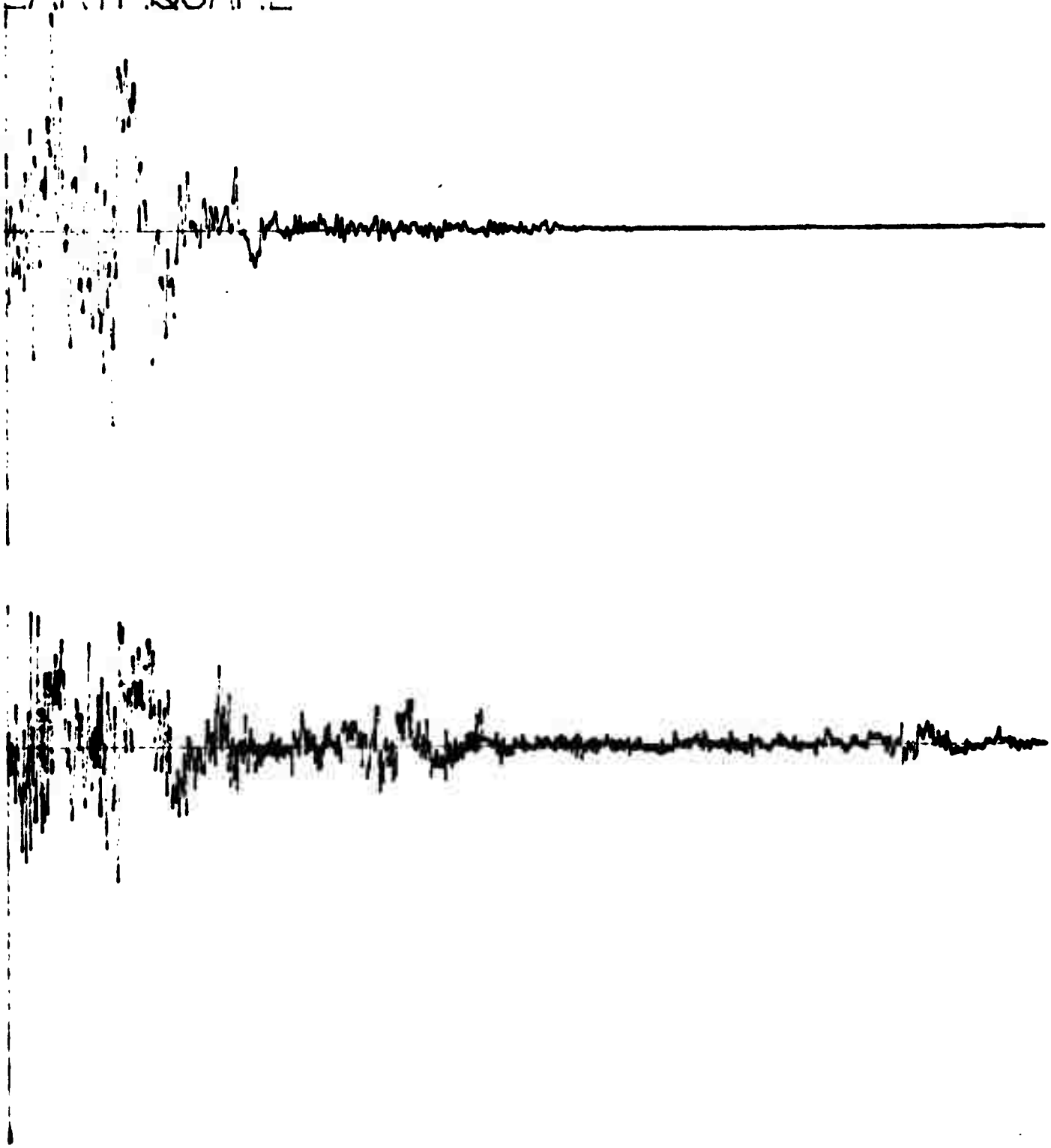
EVENT NUMBER 1266
EARTHQUAKE



Q272

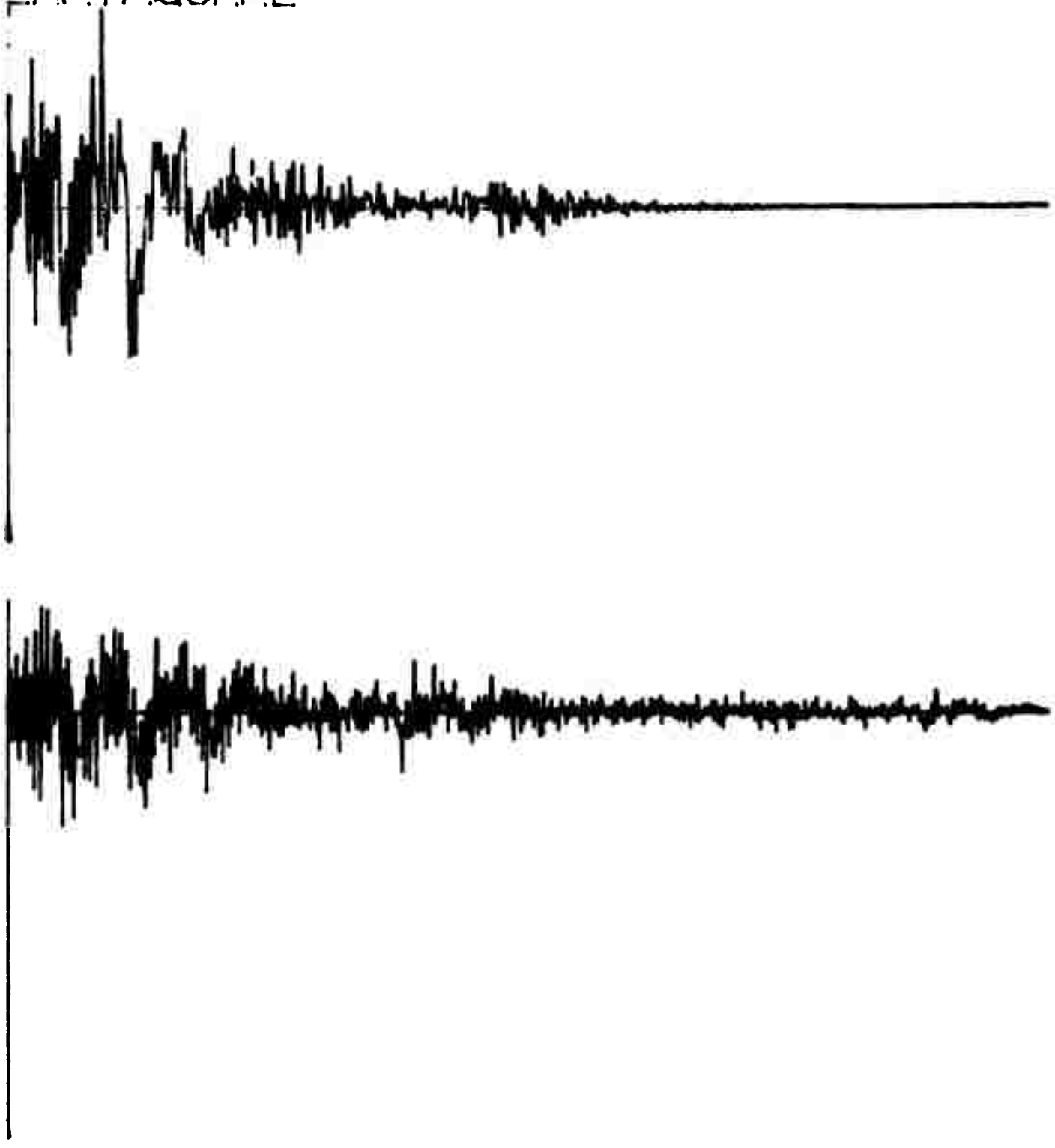
EVENT NUMBER 1272

EARTHQUAKE



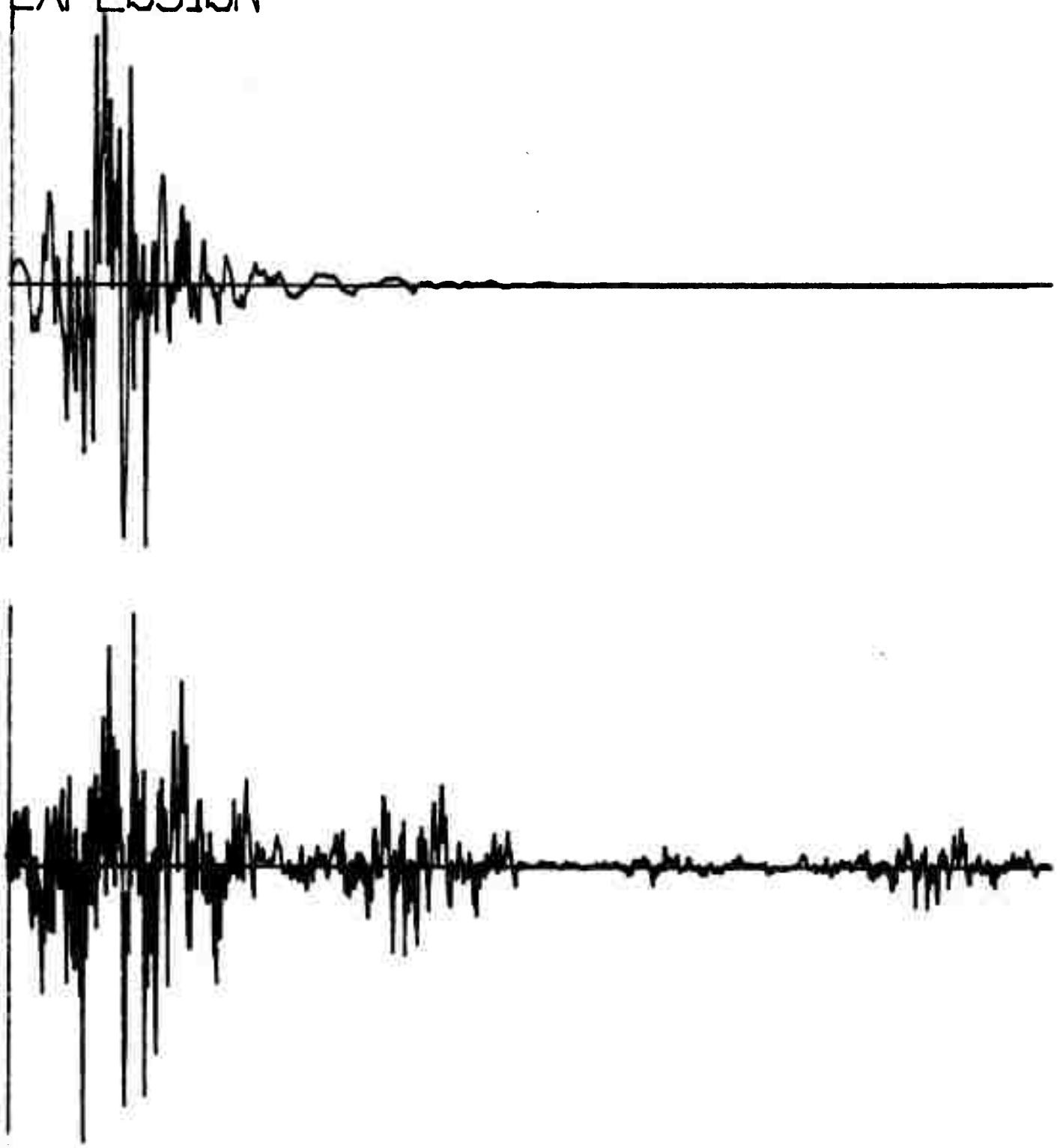
Q274

EVENT NUMBER 1273
EARTHQUAKE



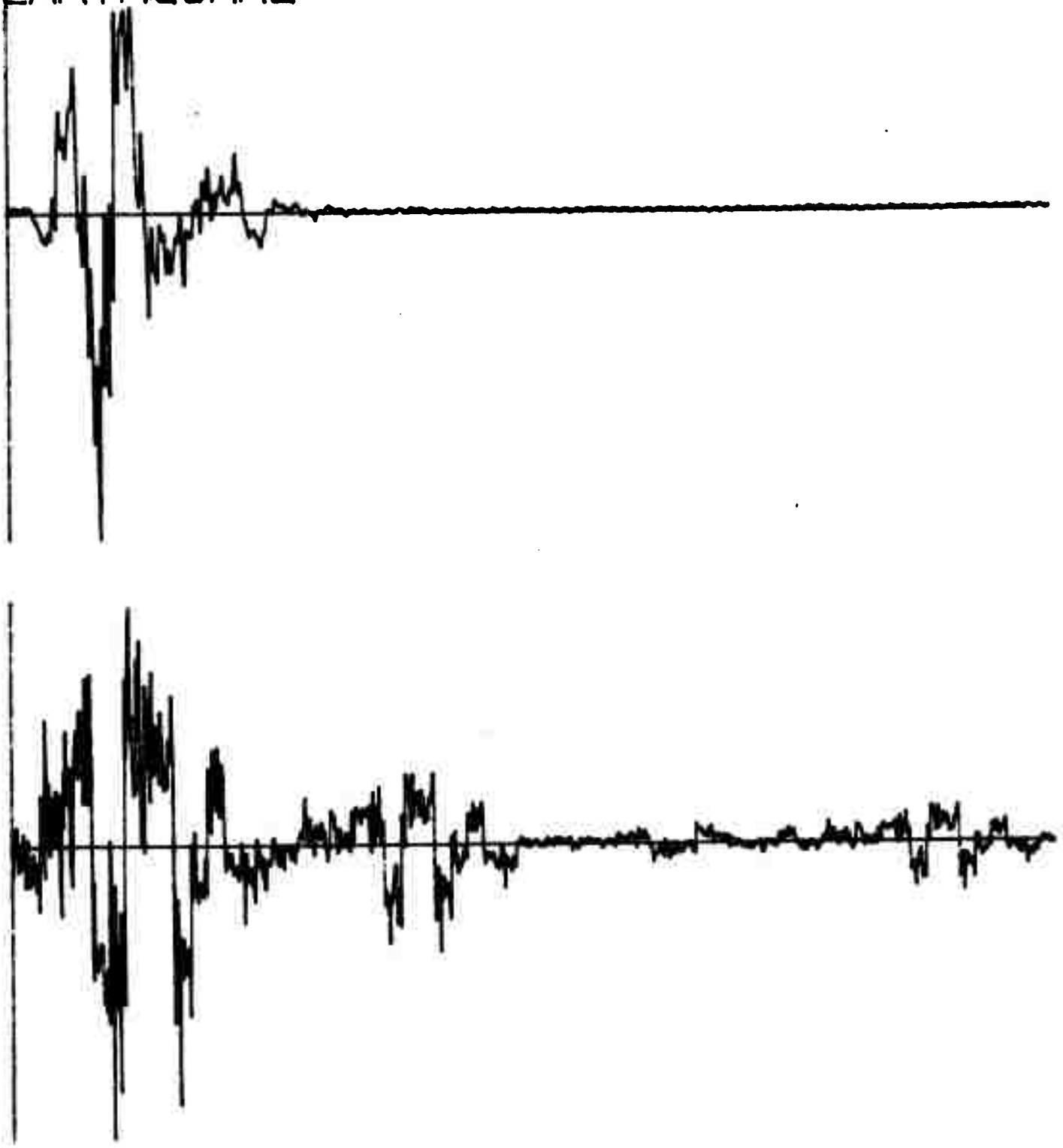
X276

EVENT NUMBER 1516
EXPLOSION



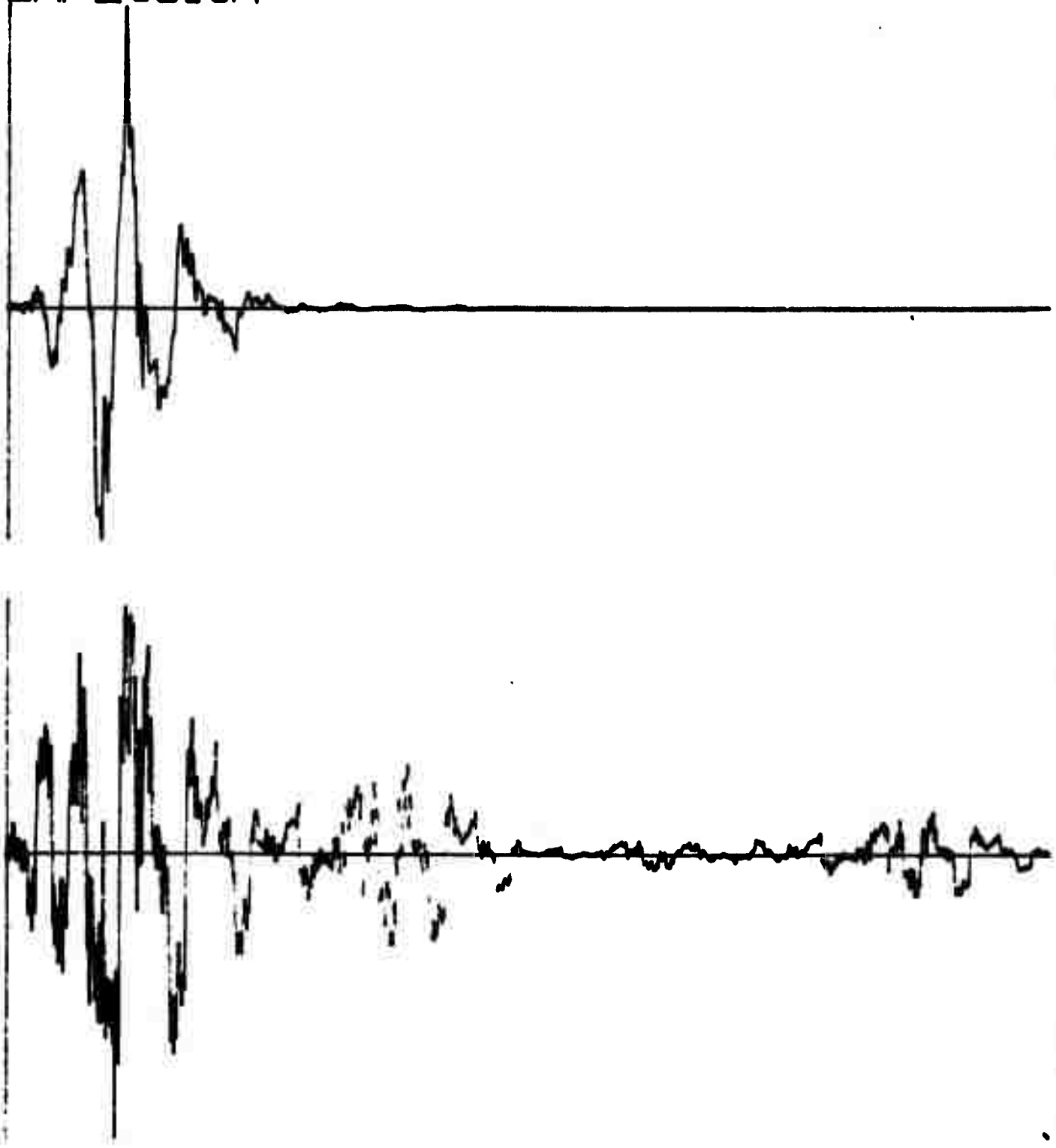
Q278

EVENT NUMBER 1543
EARTHQUAKE



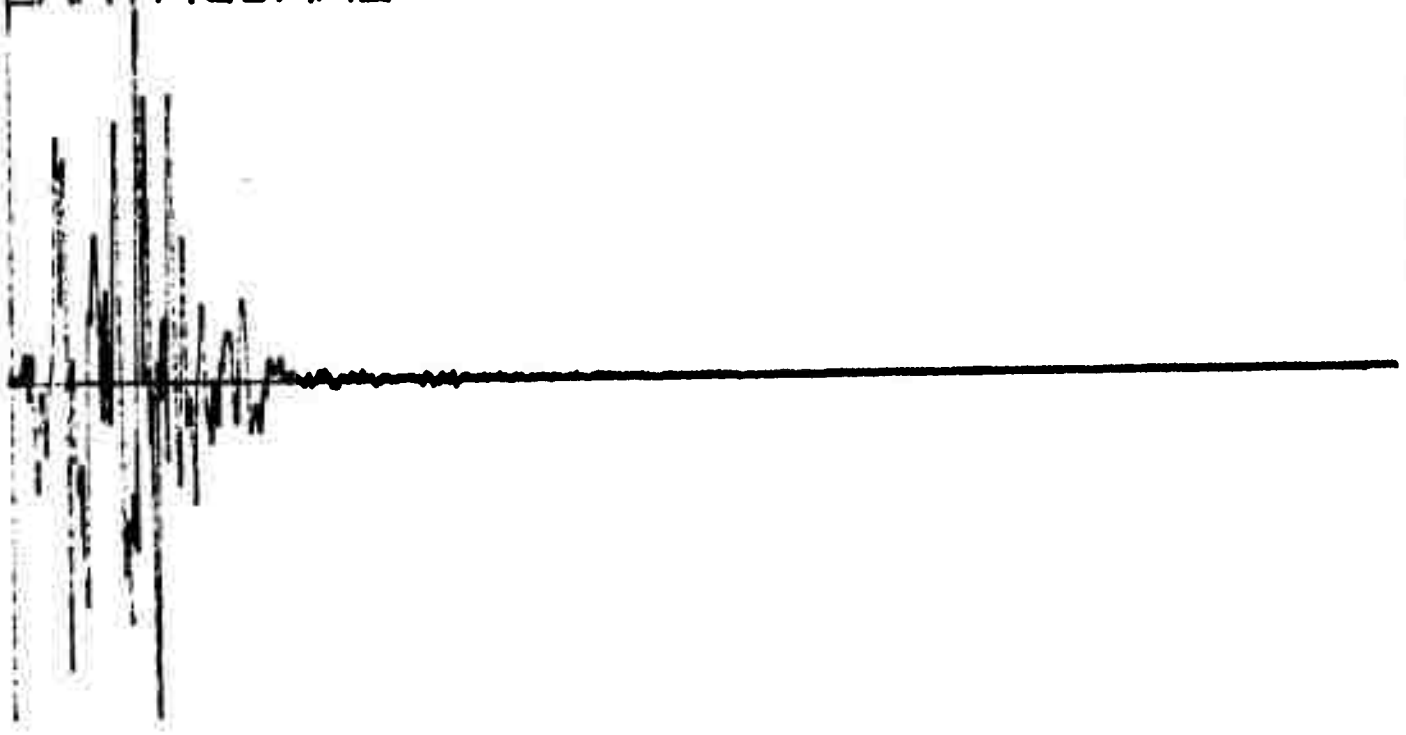
X280

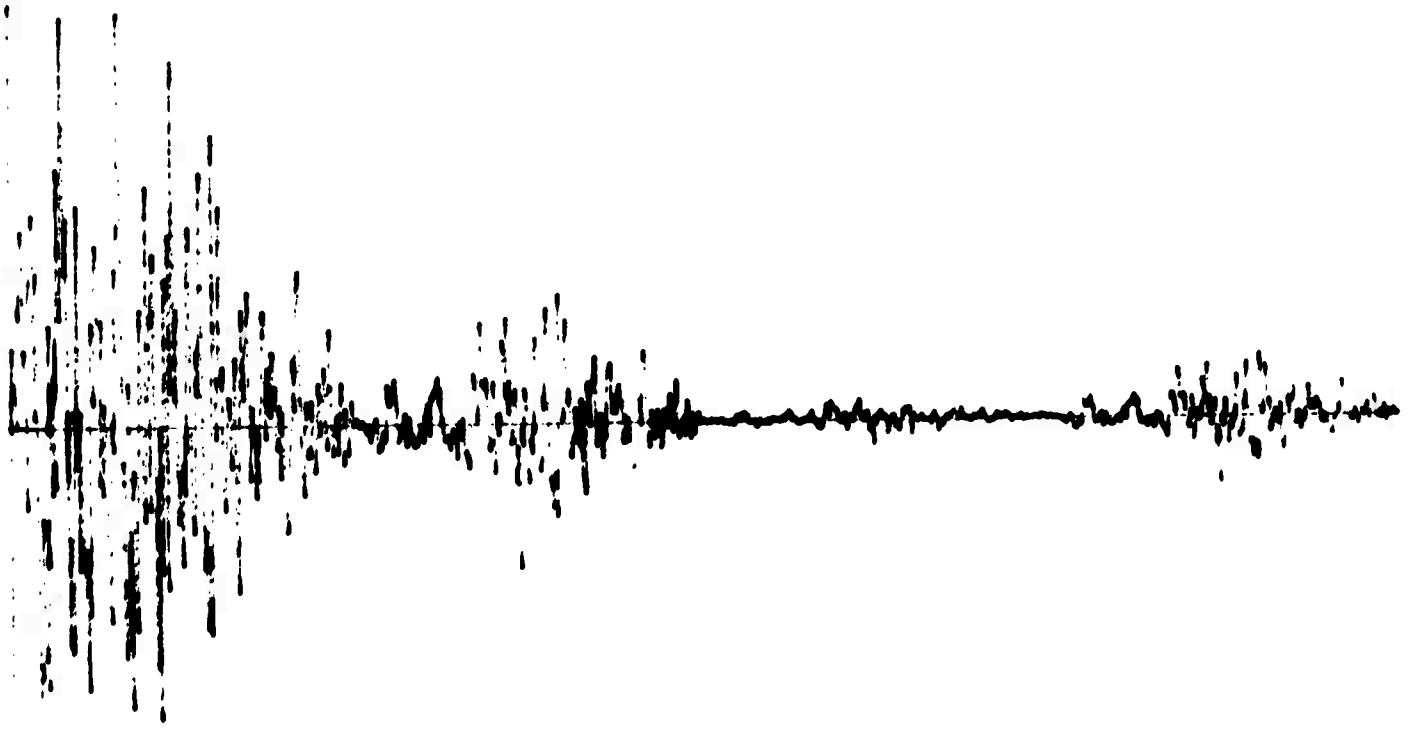
EVENT NUMBER 1510
EXPLOSION



Q282

EVENT NUMBER 2021
EARTHQUAKE

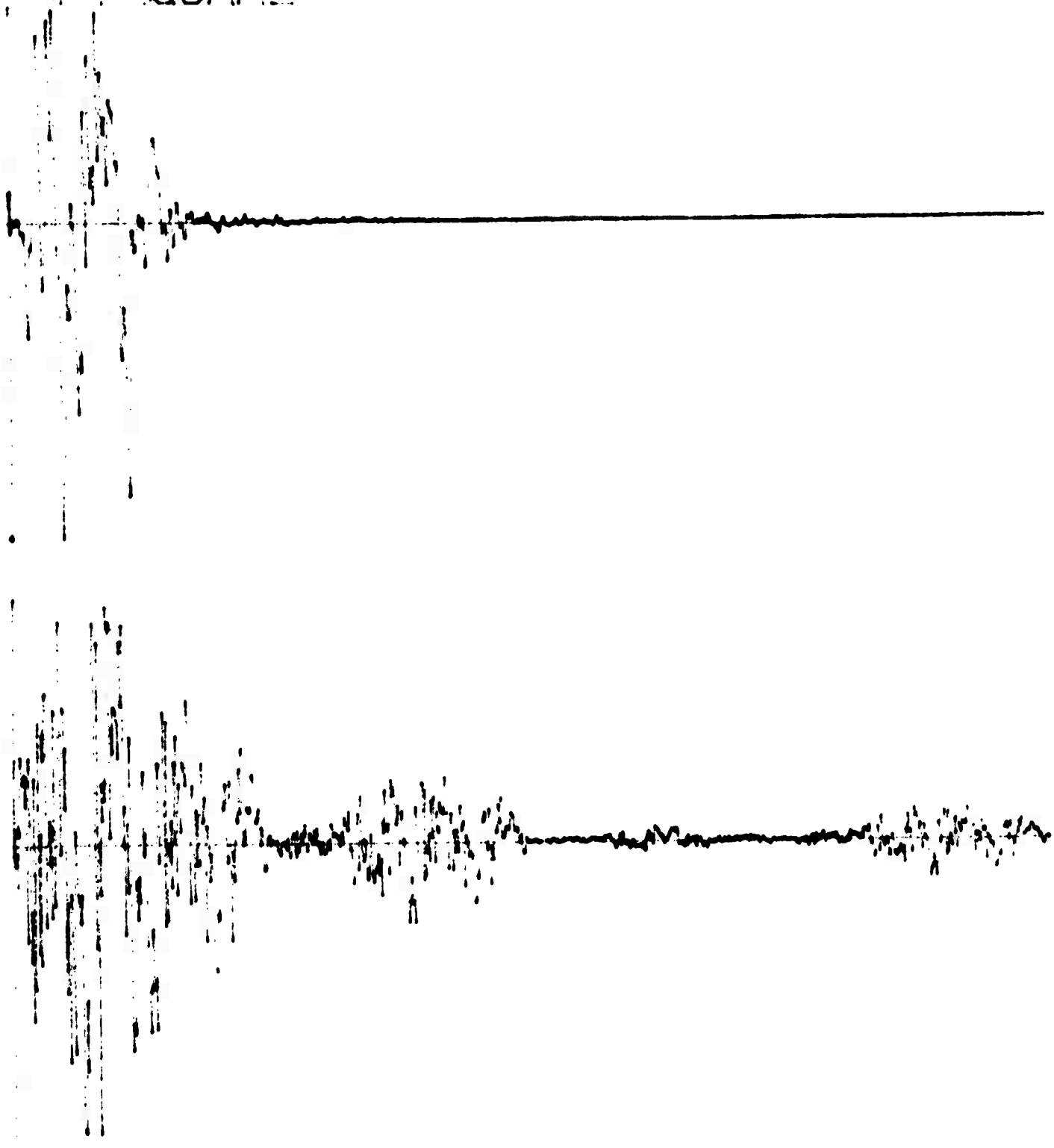


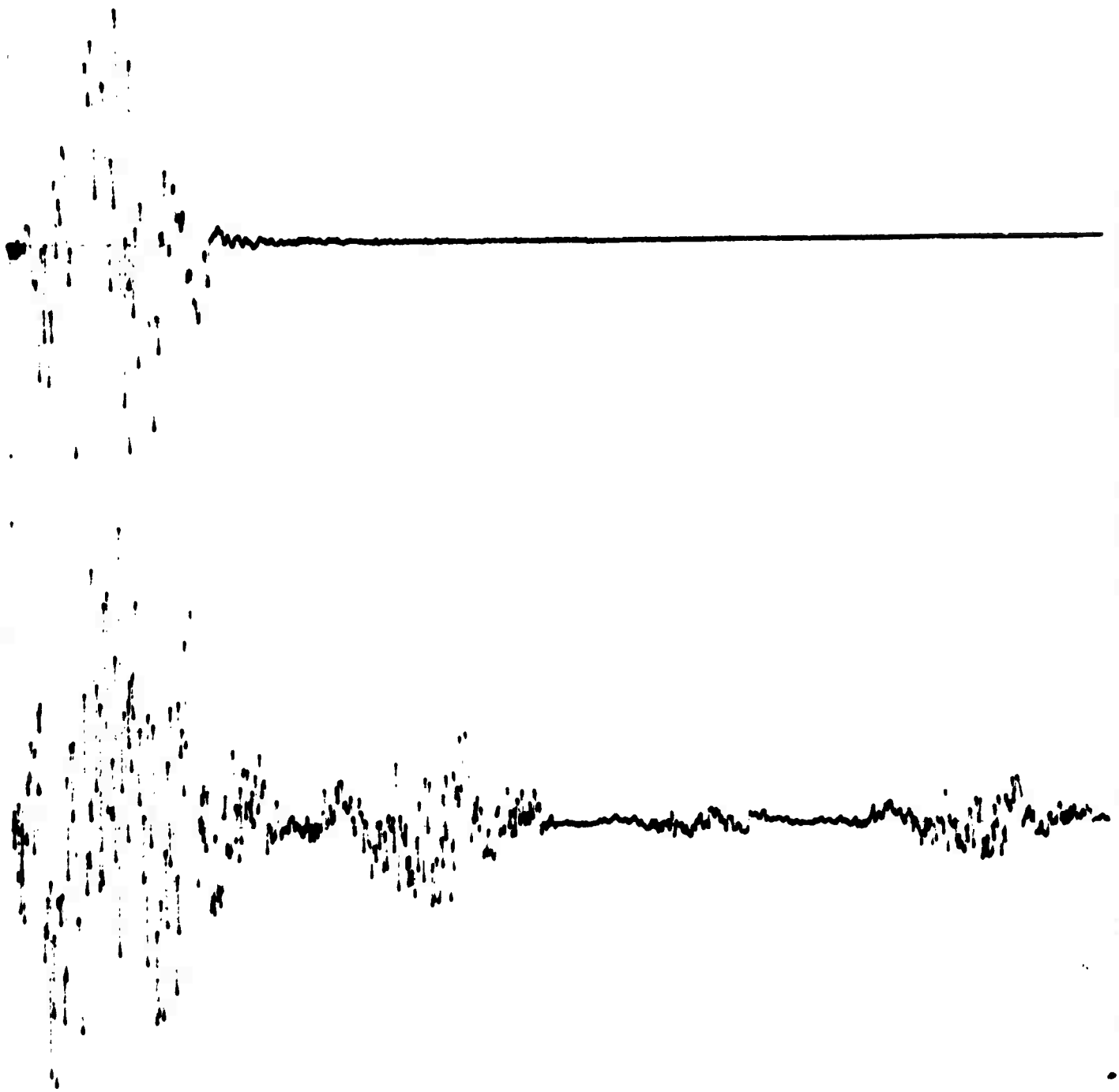


Q284

EVENT NUMBER 2013

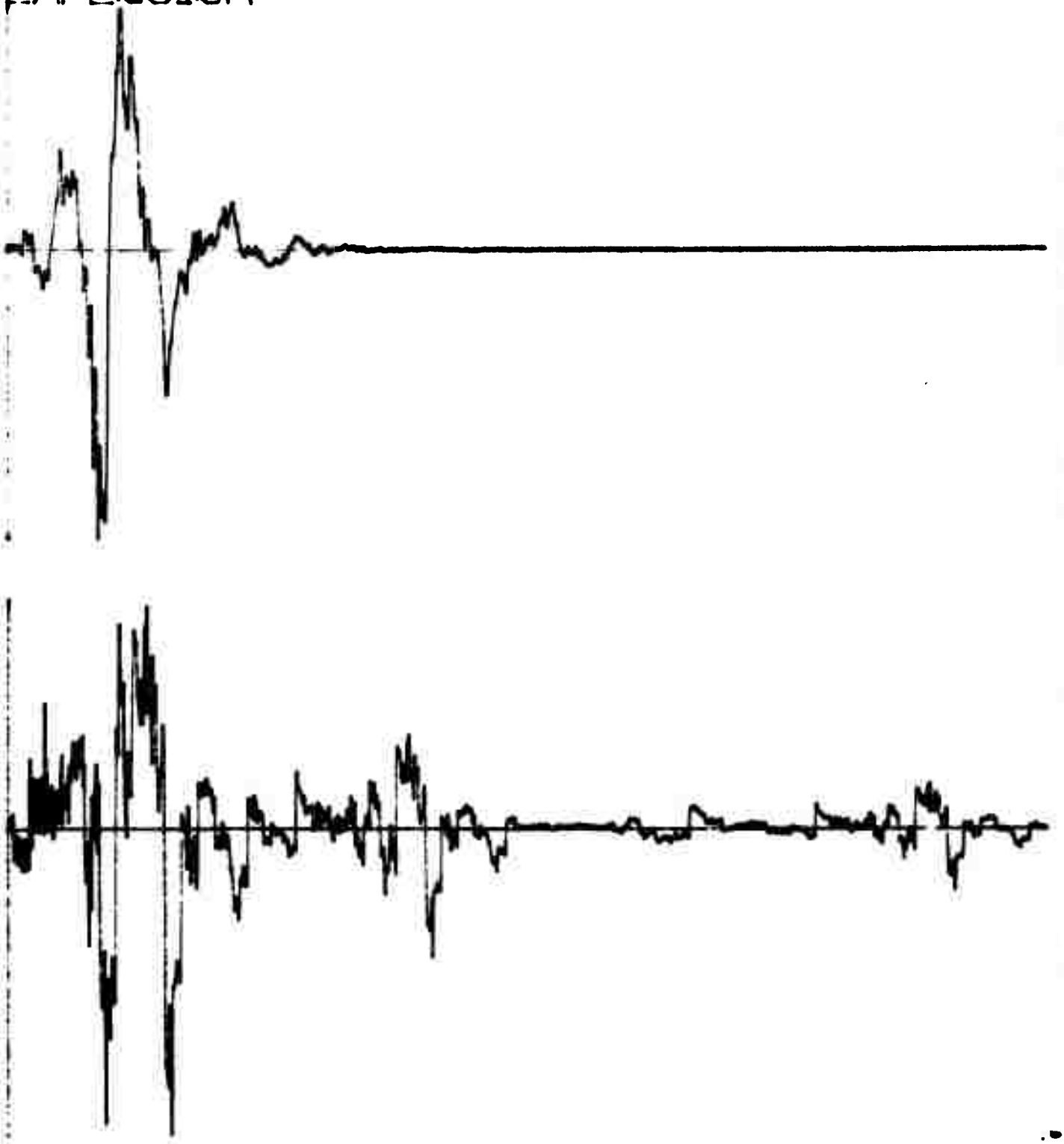
QUAKE





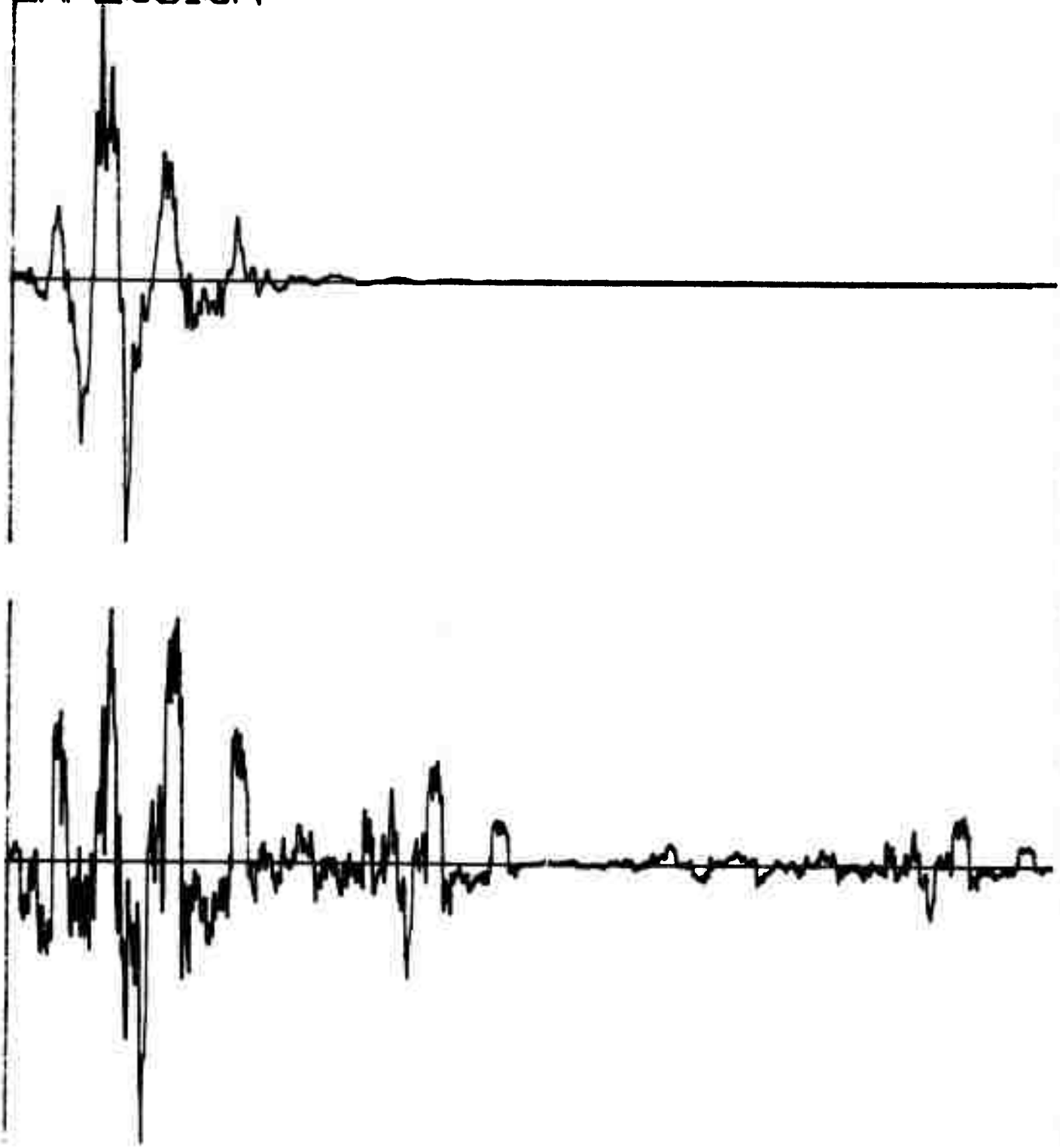
X288

EVENT NUMBER 1505
EXPLOSION

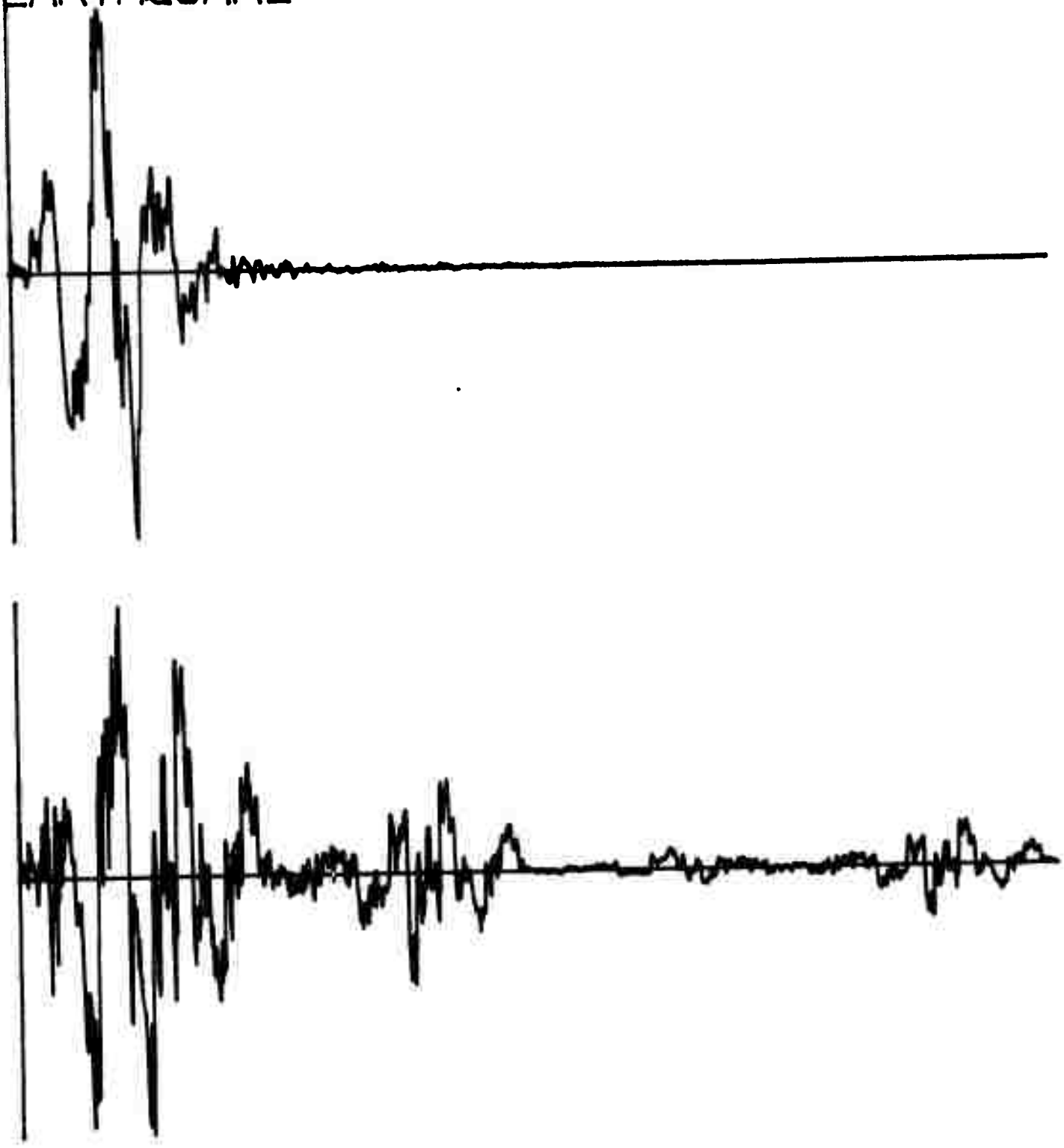


X290

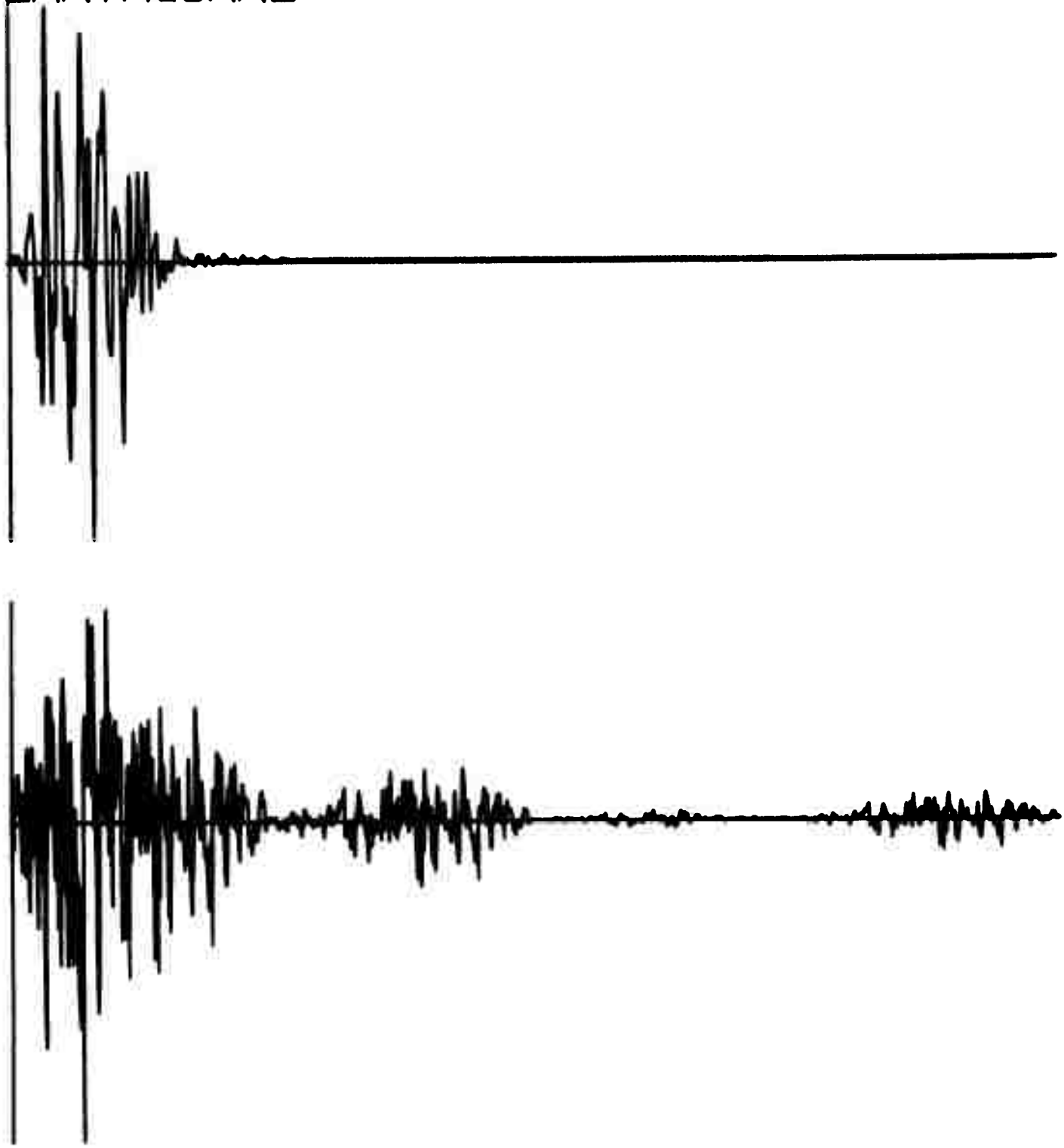
EVENT NUMBER 1503
EXPLOSION



EVENT NUMBER 2004
EARTHQUAKE

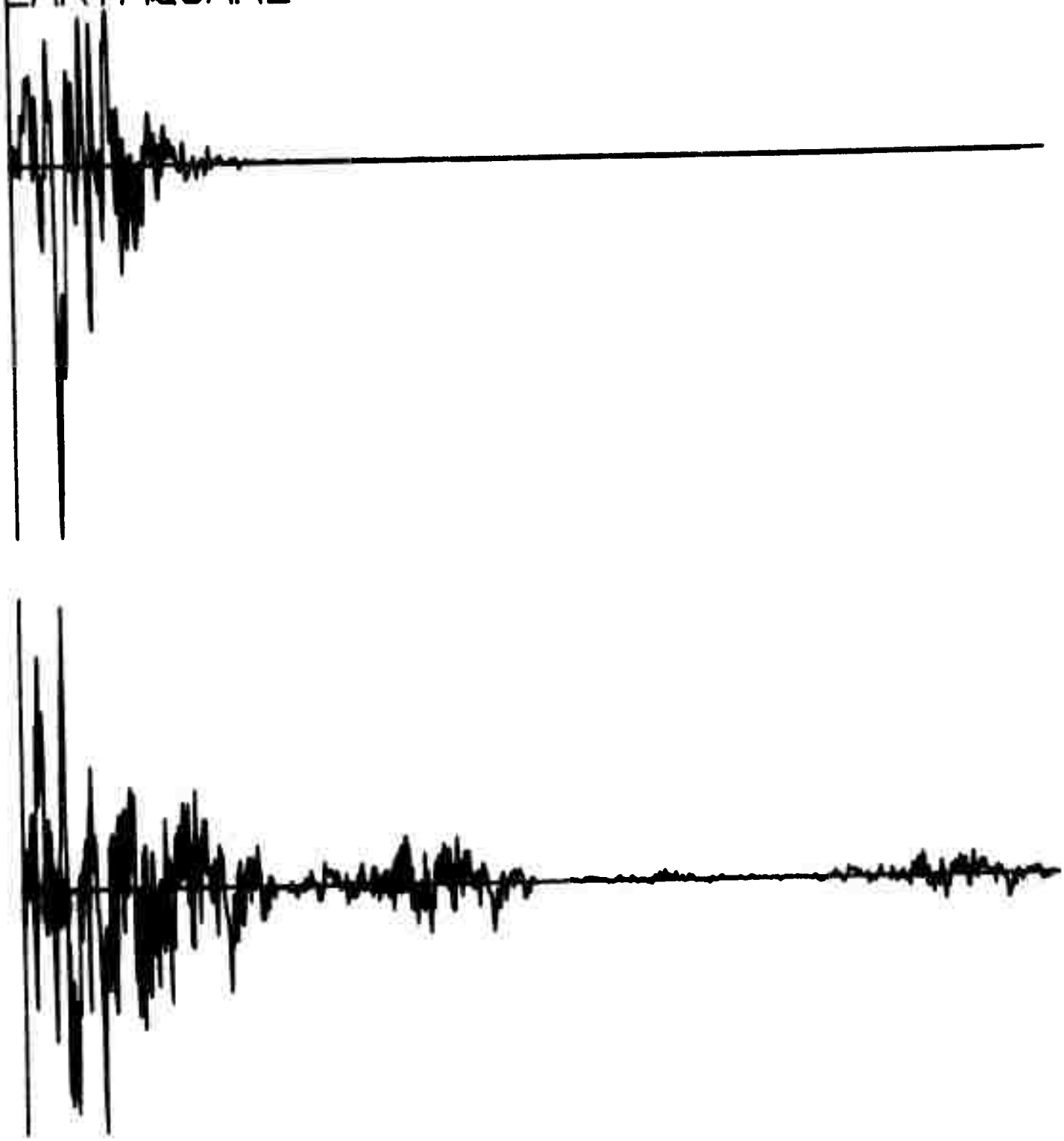


EVENT NUMBER 2007
EARTHQUAKE

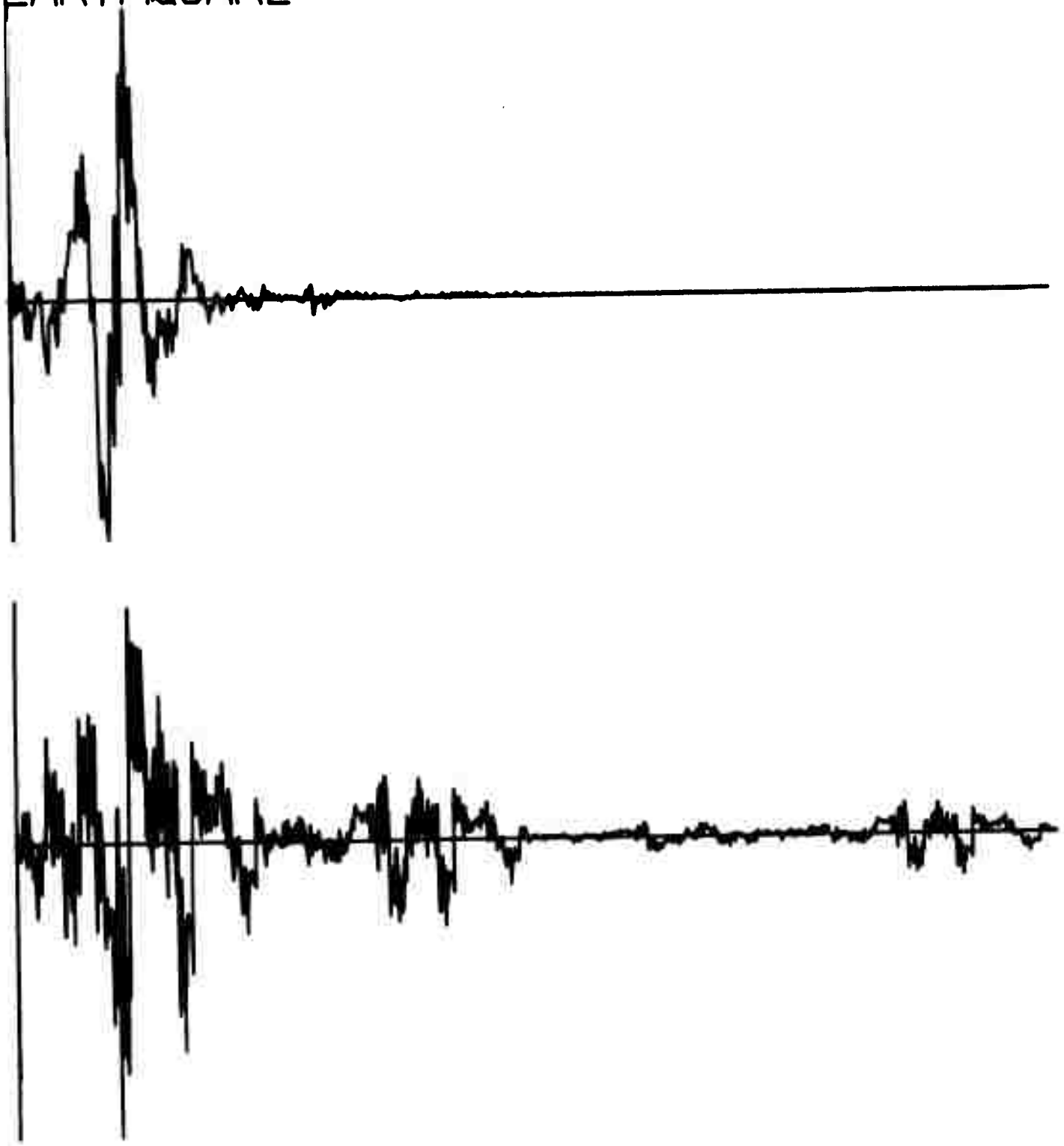


Q296

EVENT NUMBER 2015
EARTHQUAKE

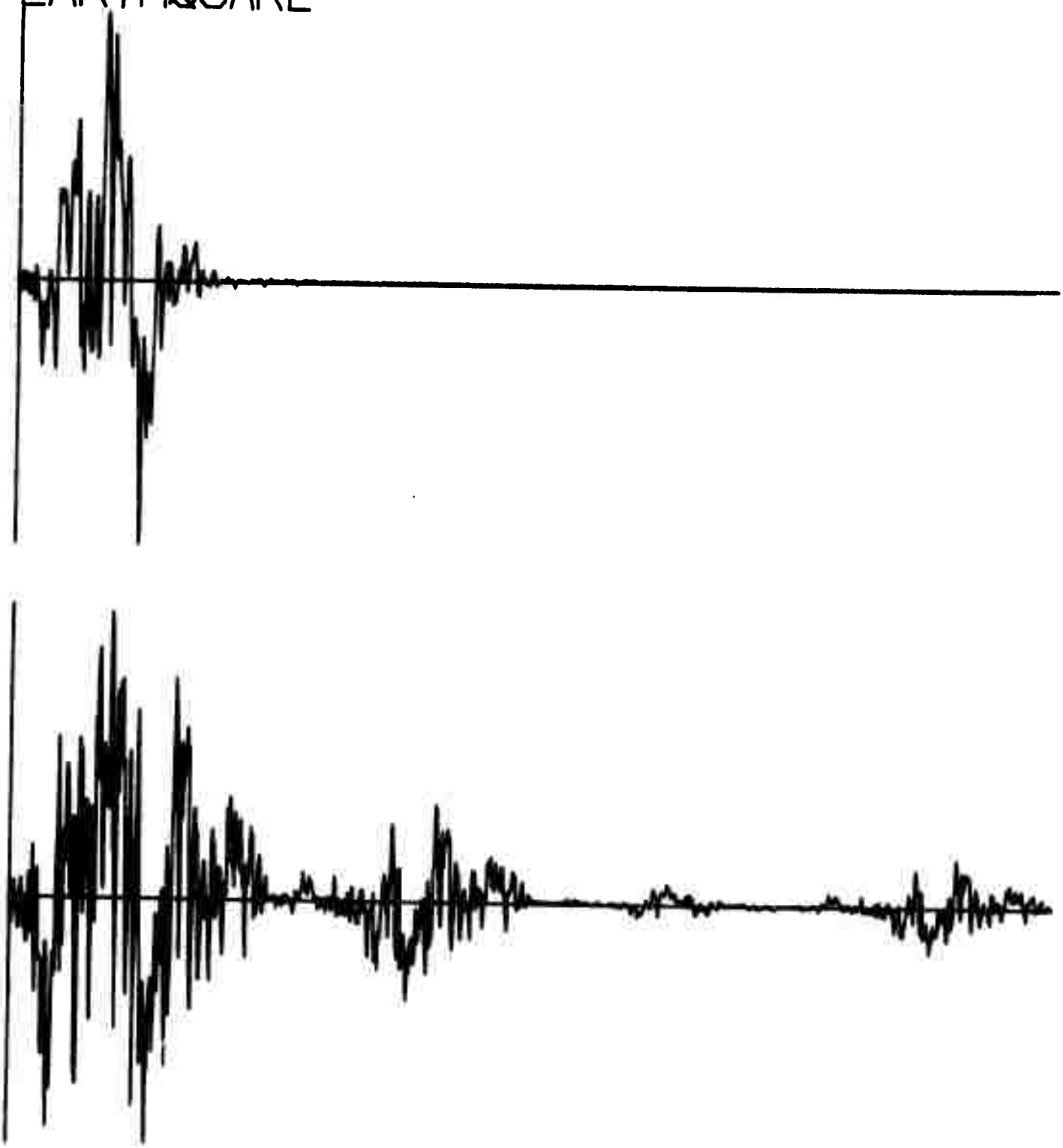


EVENT NUMBER 1300
EARTHQUAKE



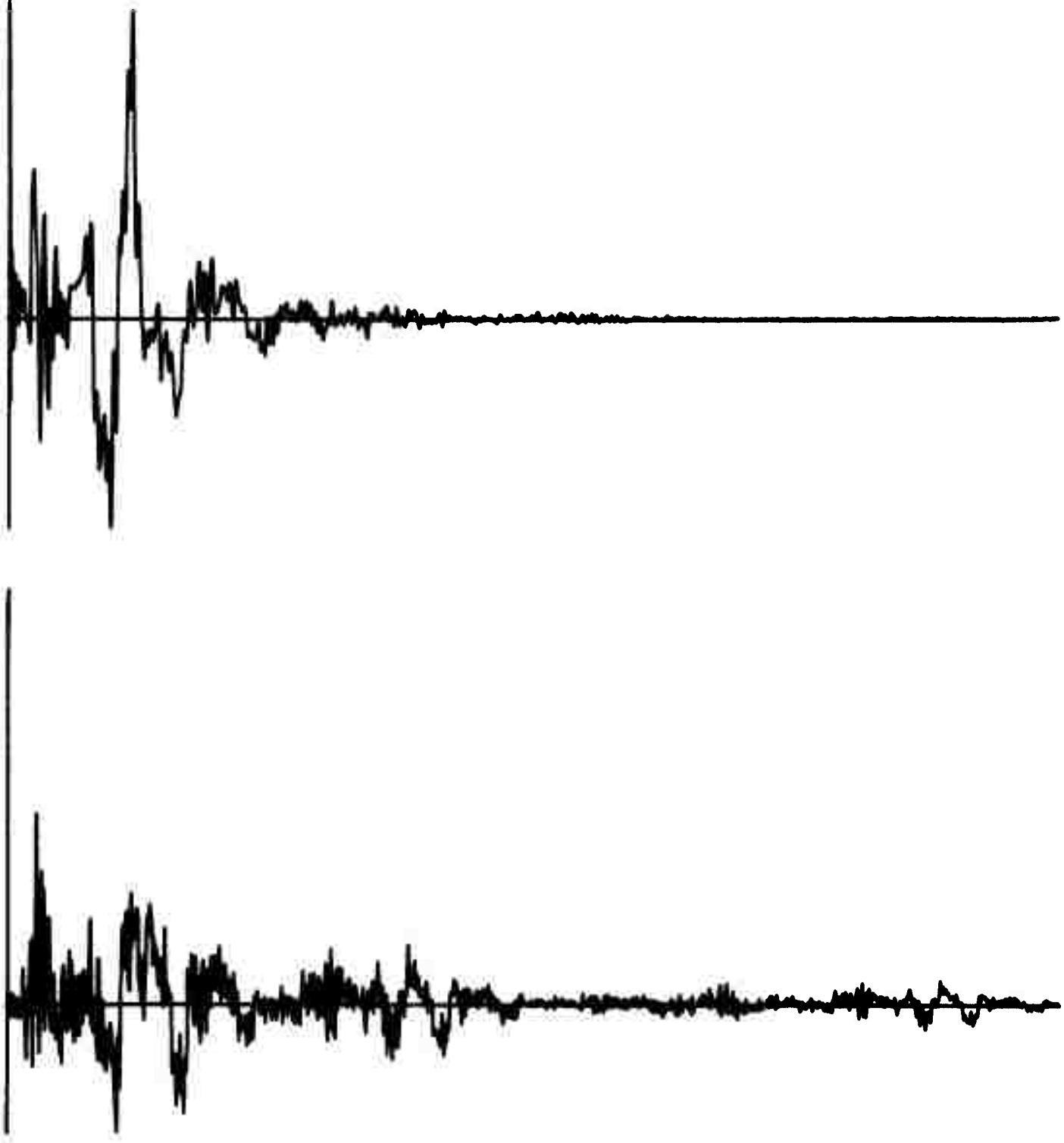
EVENT NUMBER 1301
EARTHQUAKE

Q300

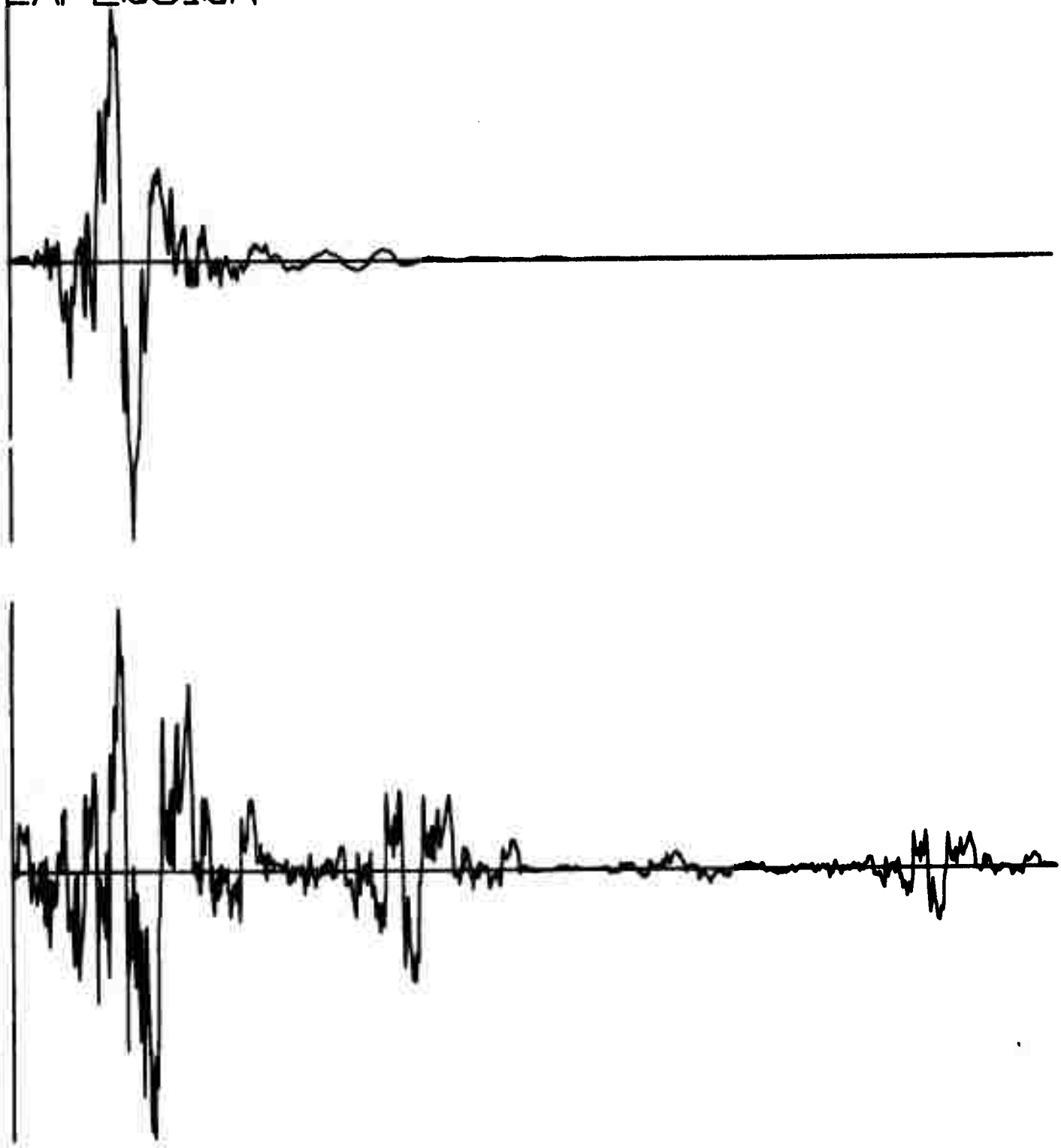


X302

EVENT NUMBER 1535
EXPLOSION

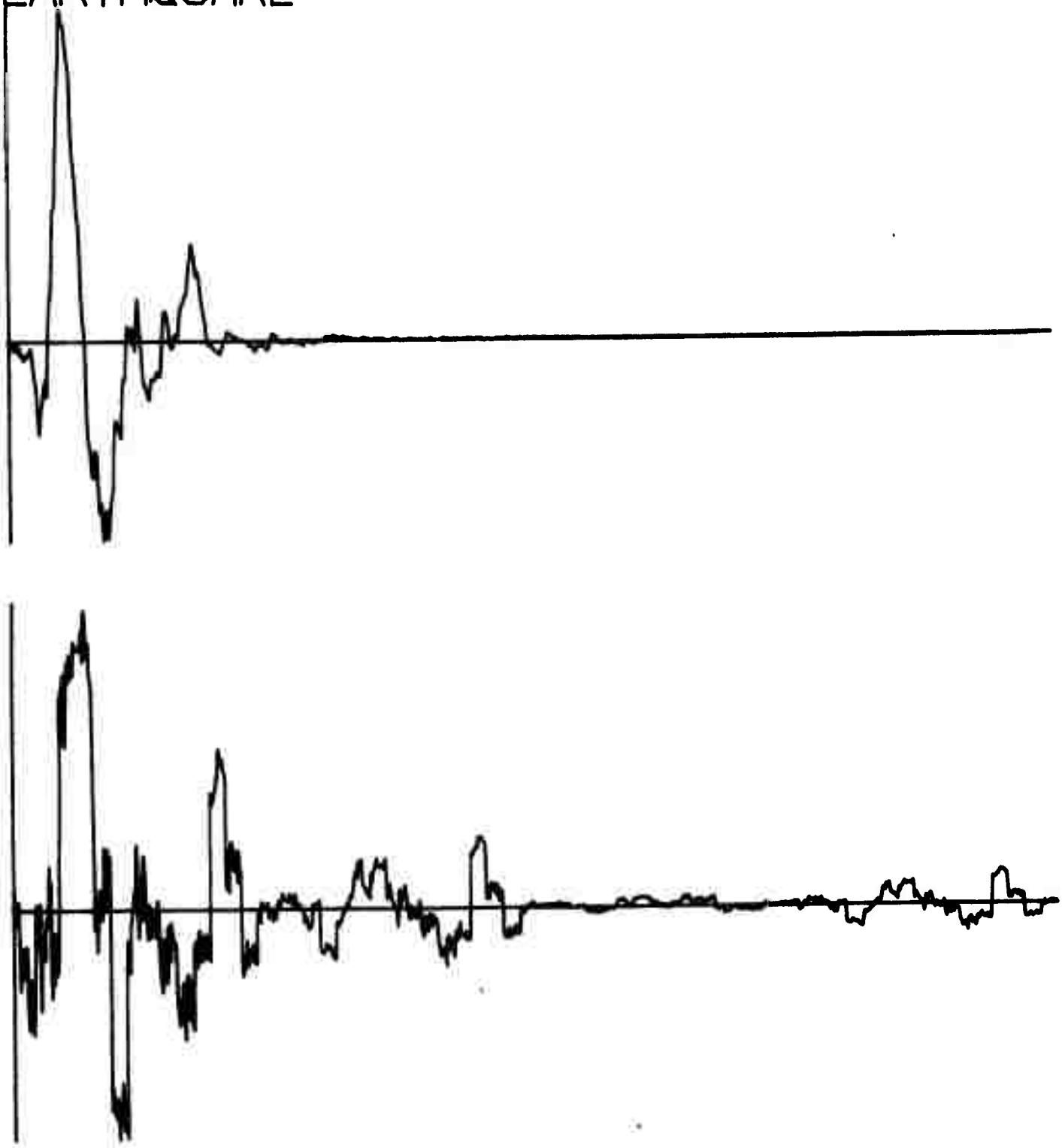


EVENT NUMBER 1506
EXPLOSION



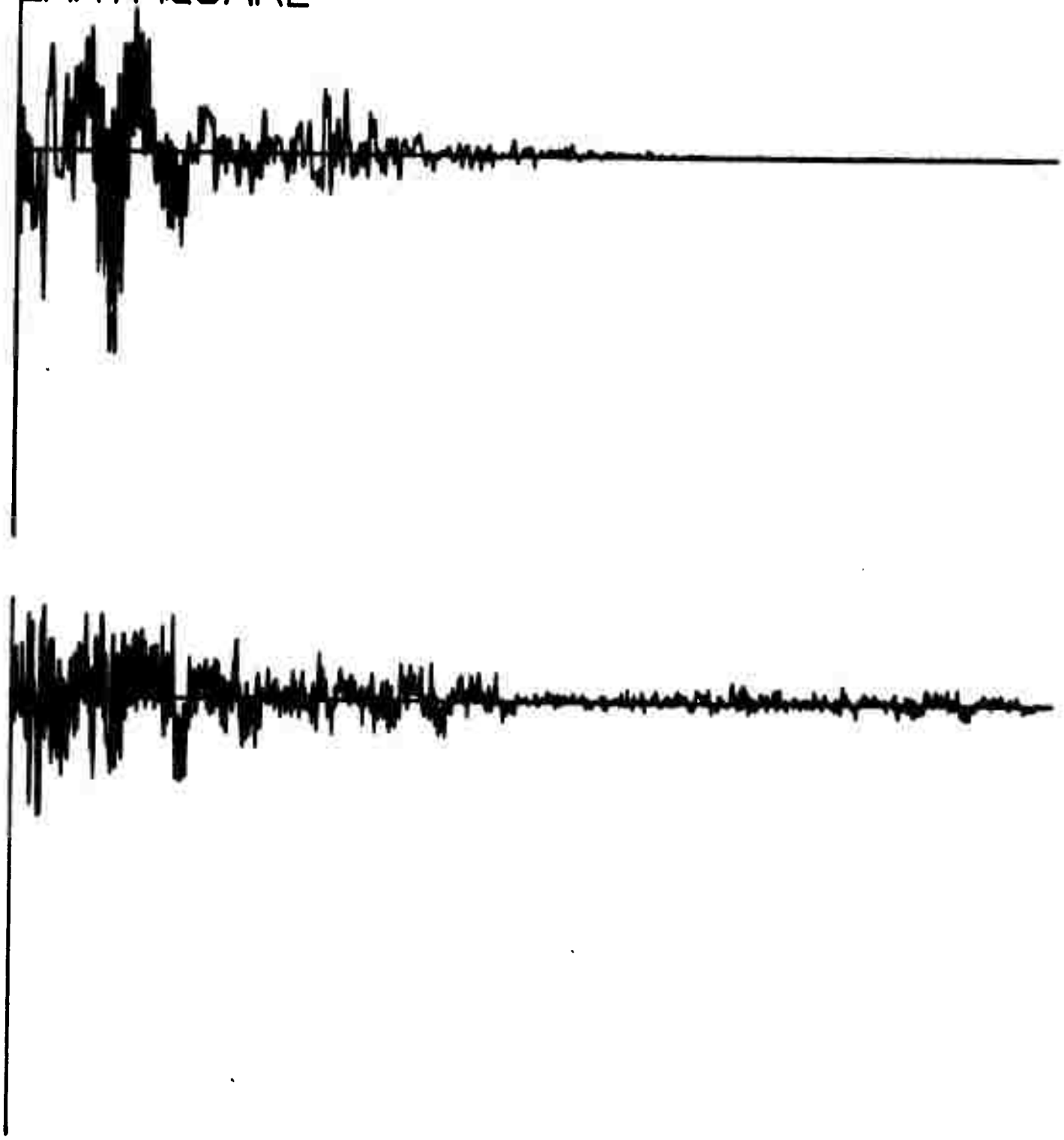
Q306

EVENT NUMBER 2022
EARTHQUAKE



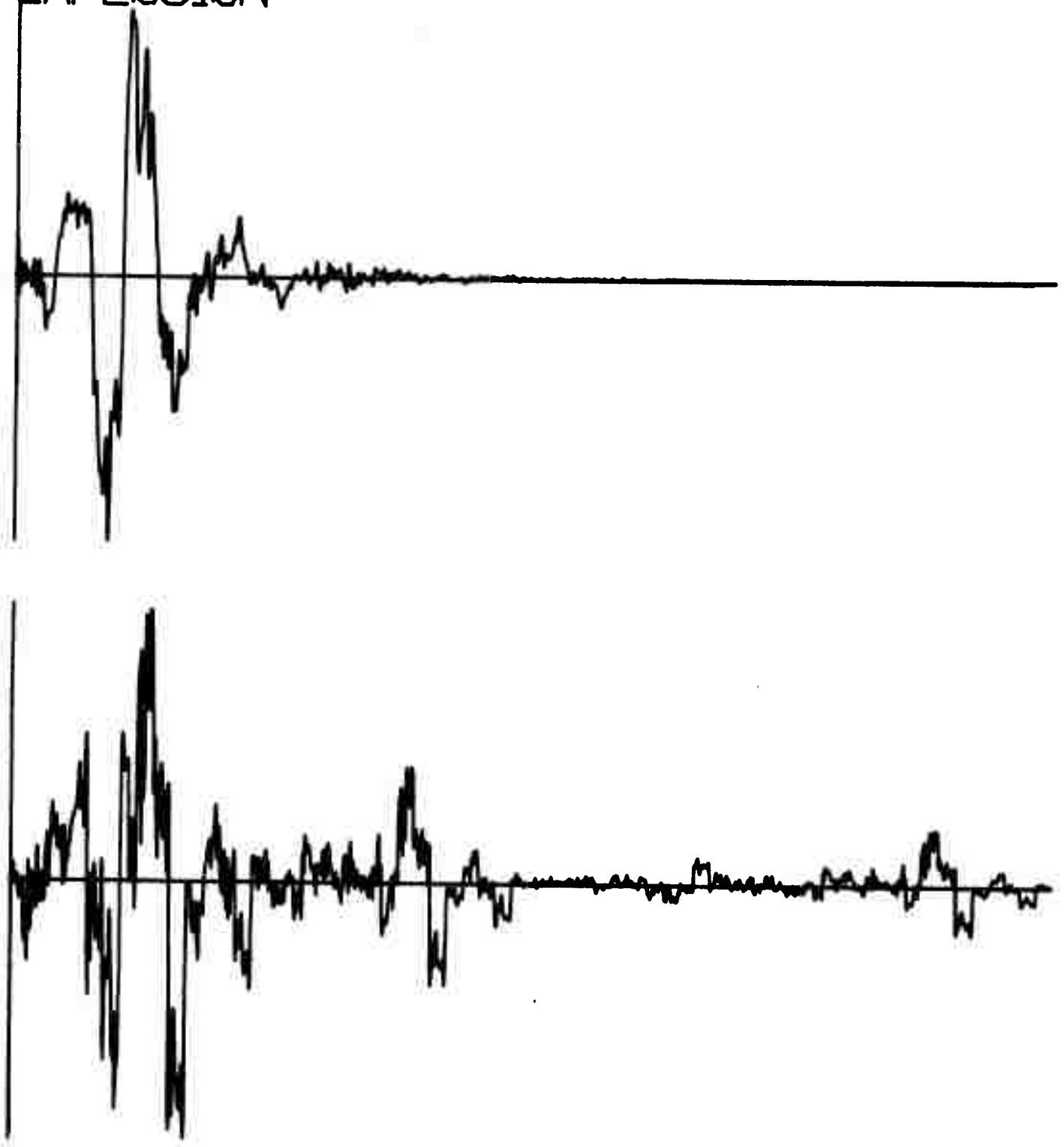
Q308

EVENT NUMBER 1310
EARTHQUAKE



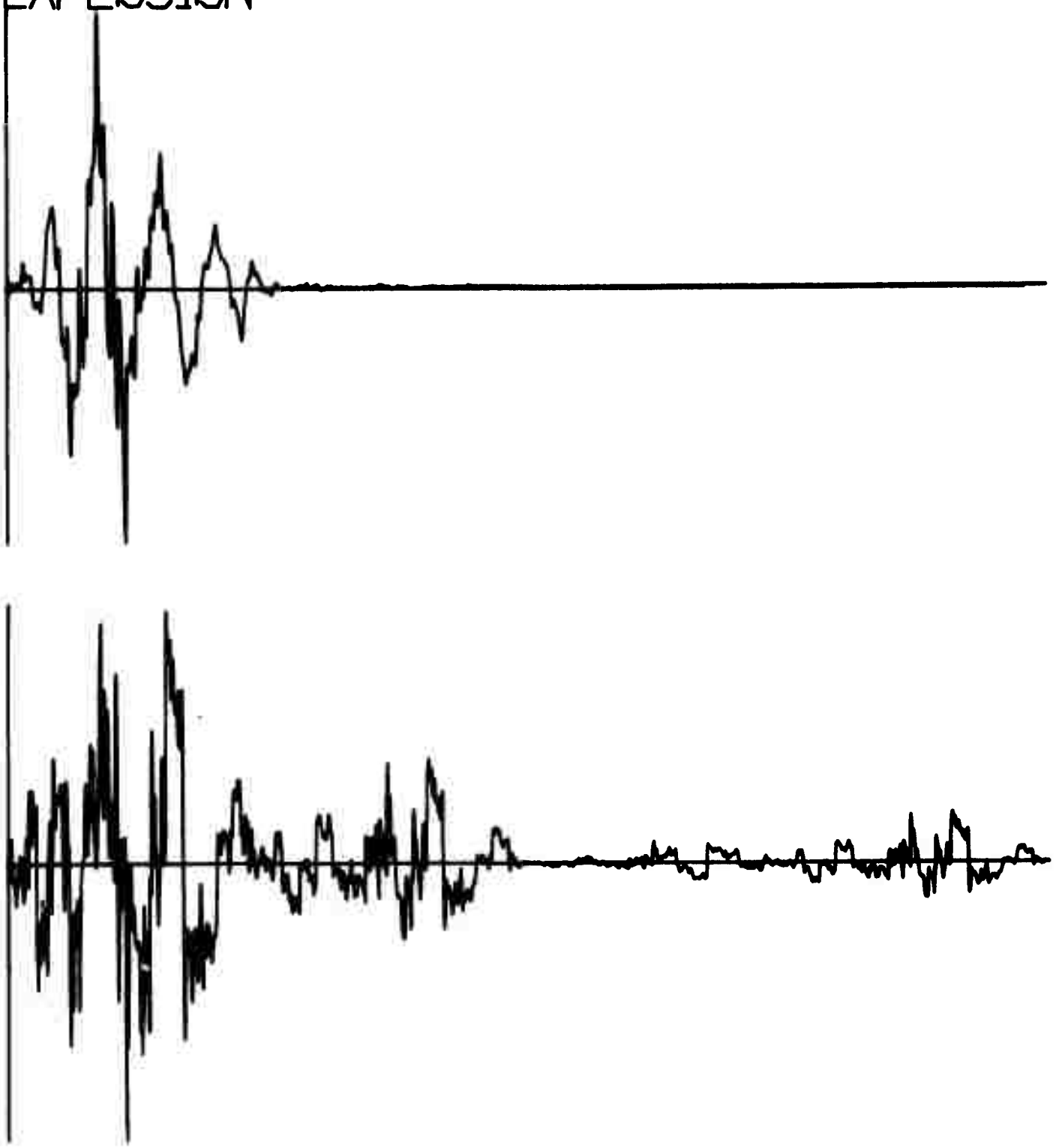
X310

EVENT NUMBER 1542
EXPLOSION

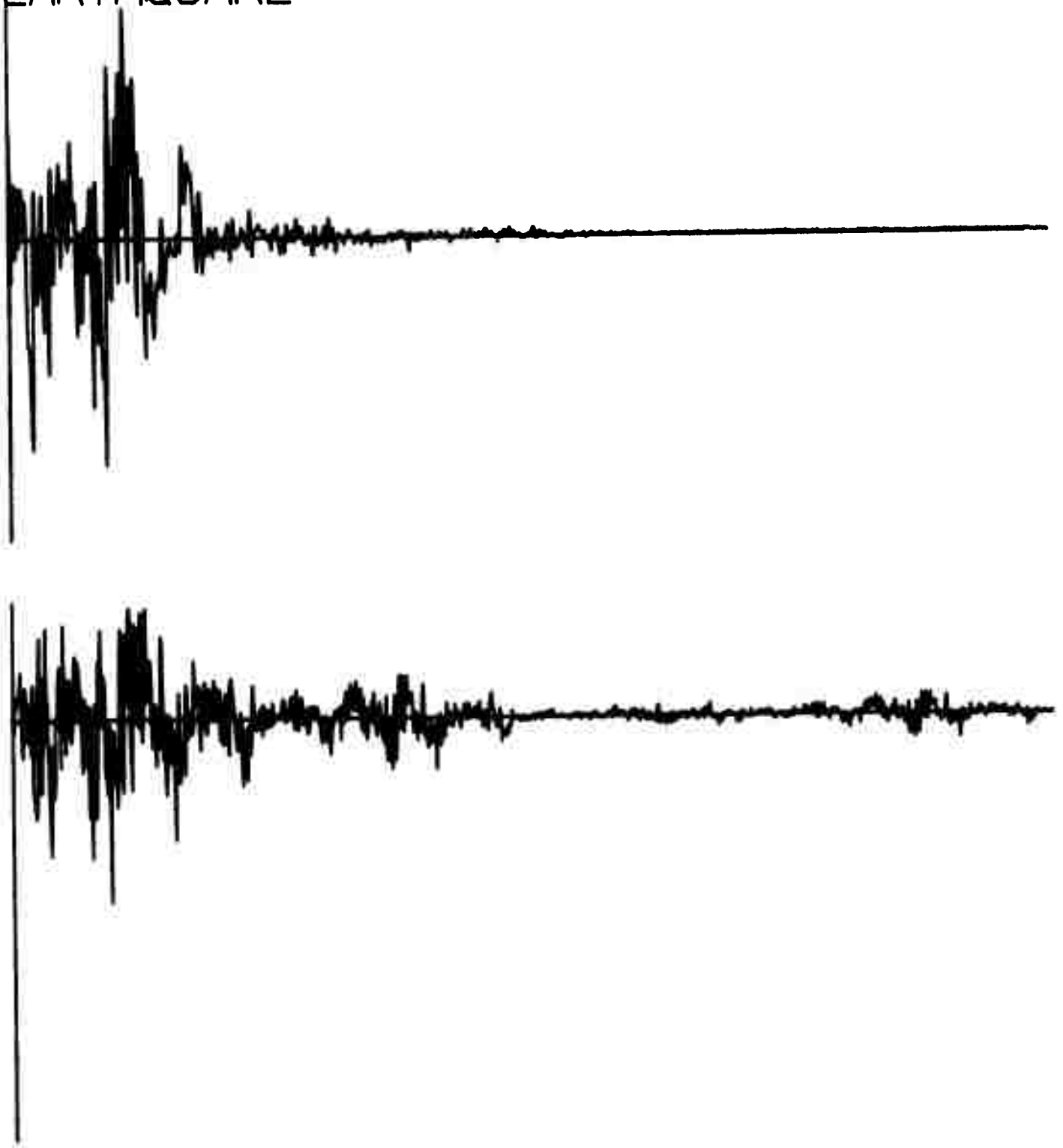


X312

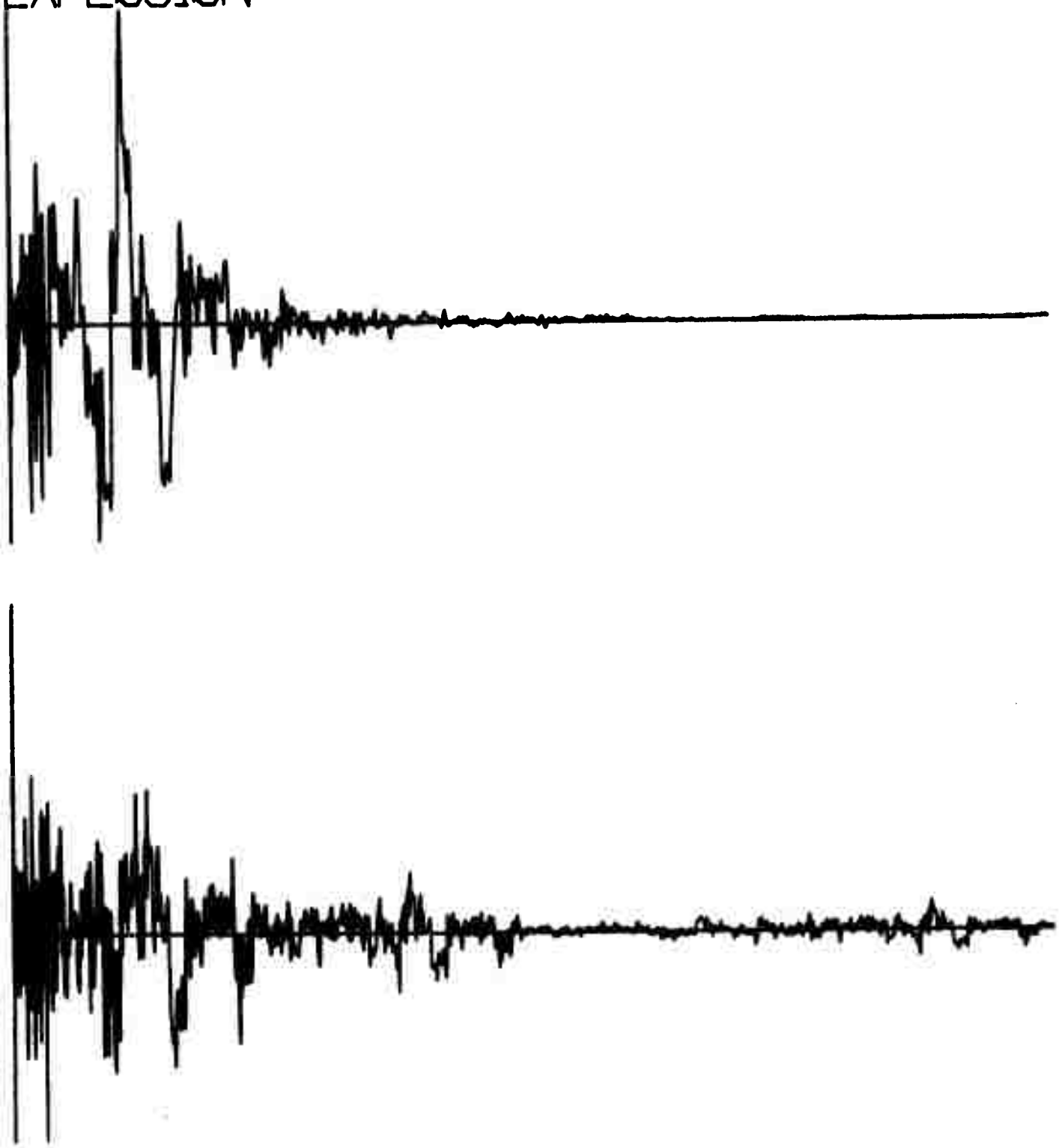
EVENT NUMBER 1541
EXPLOSION



EVENT NUMBER 1304
EARTHQUAKE

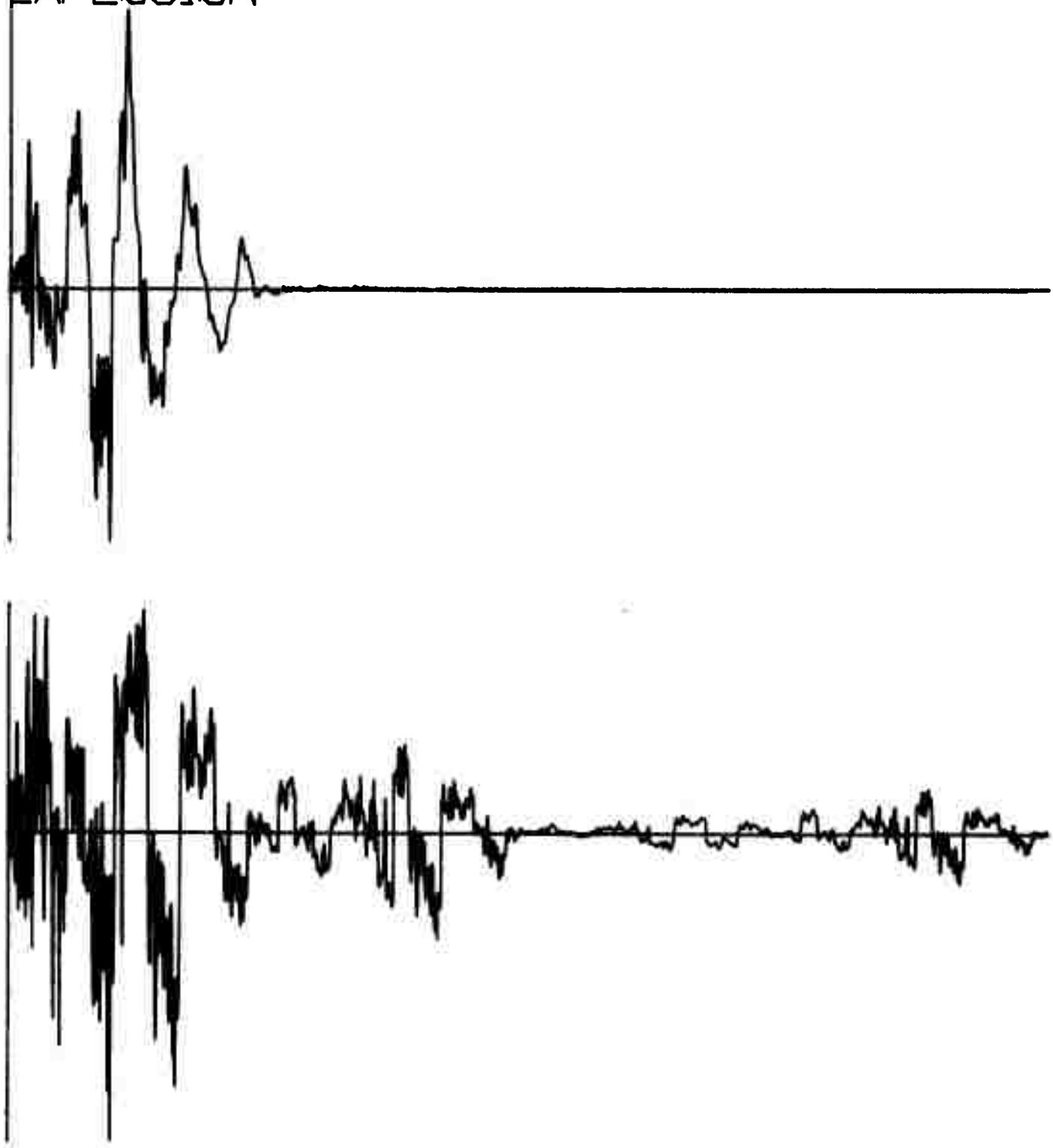


EVENT NUMBER 1501
EXPLOSION



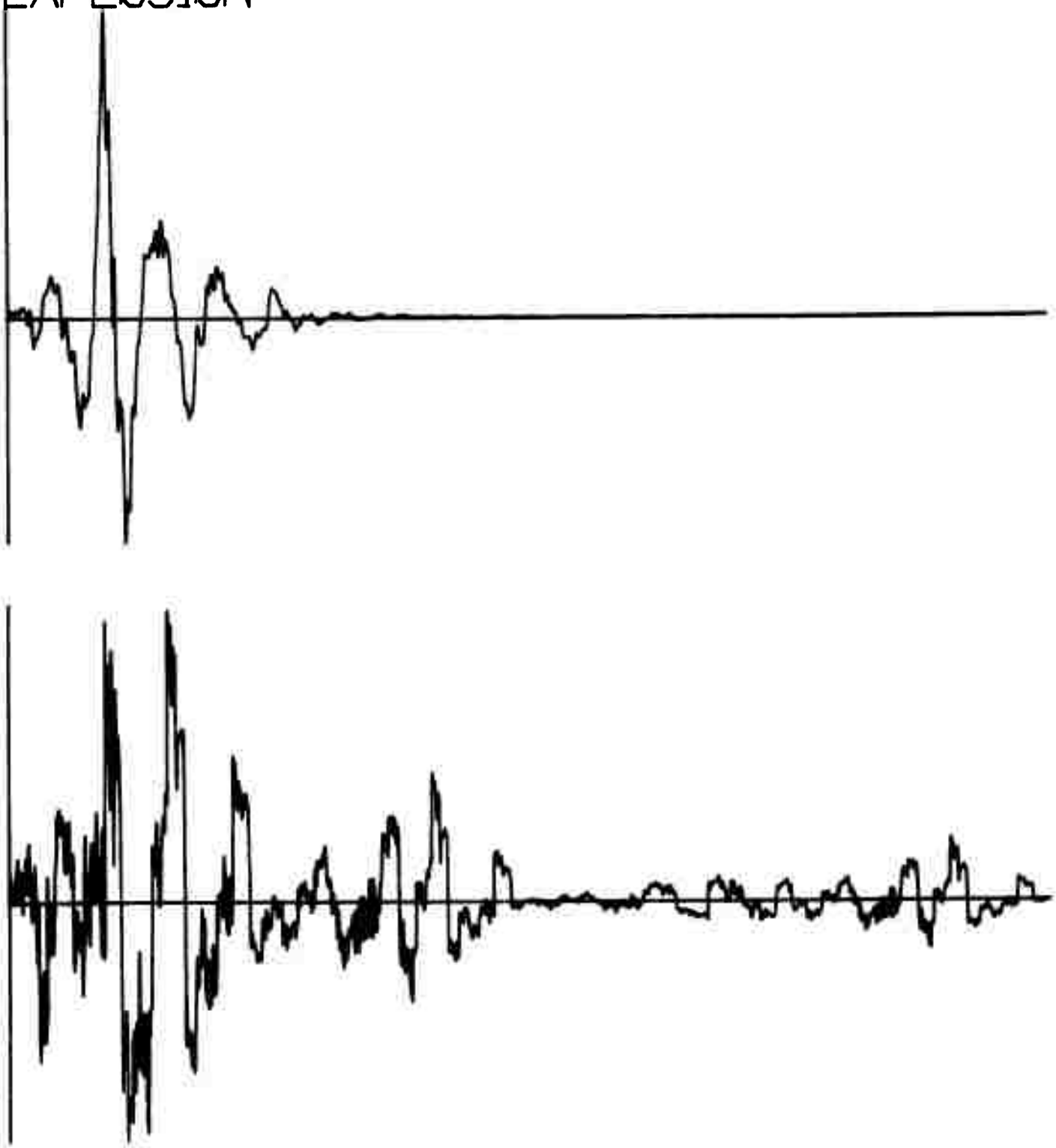
X318

EVENT NUMBER 1508
EXPLOSION



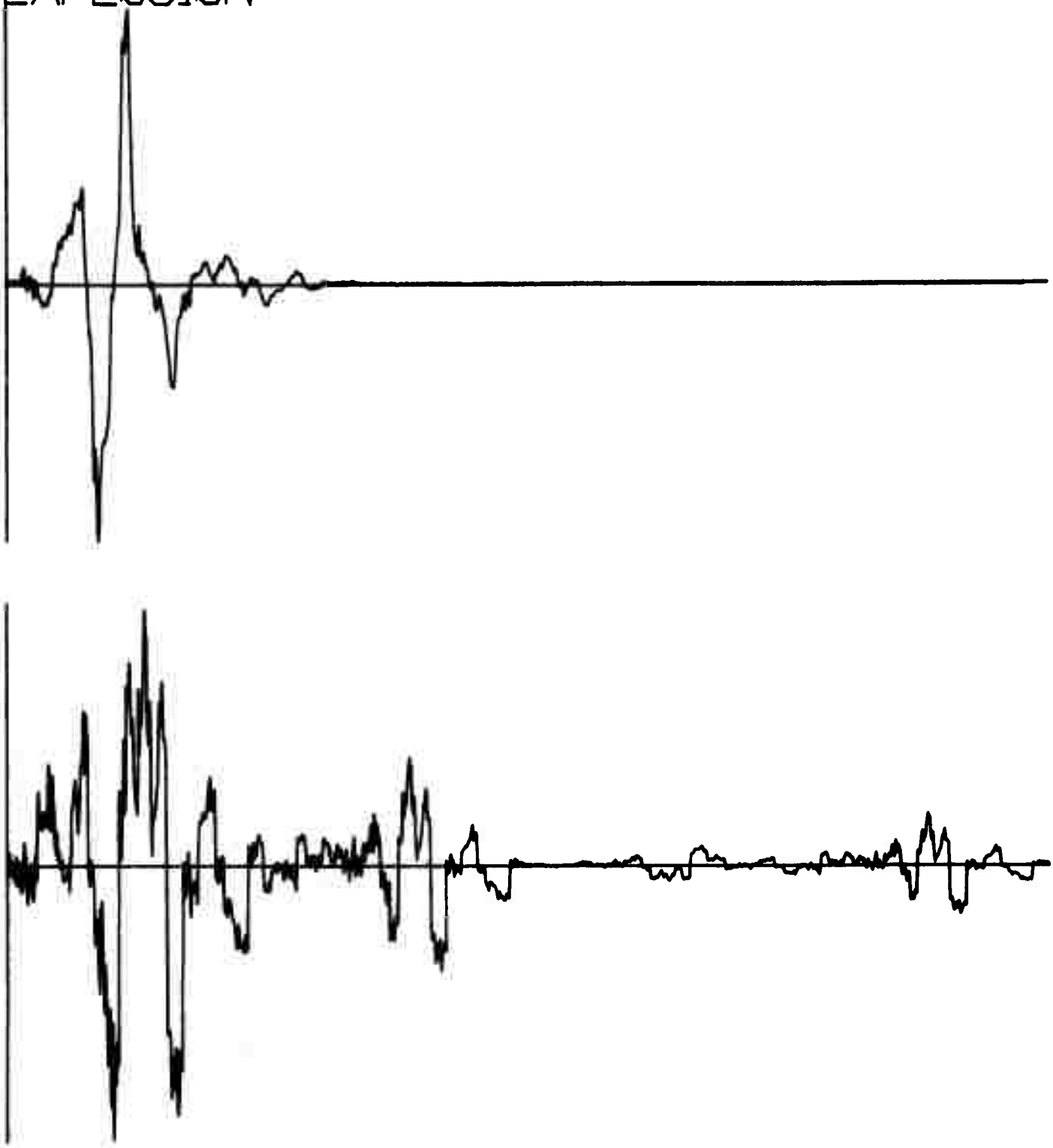
X320

EVENT NUMBER 1523
EXPLOSION



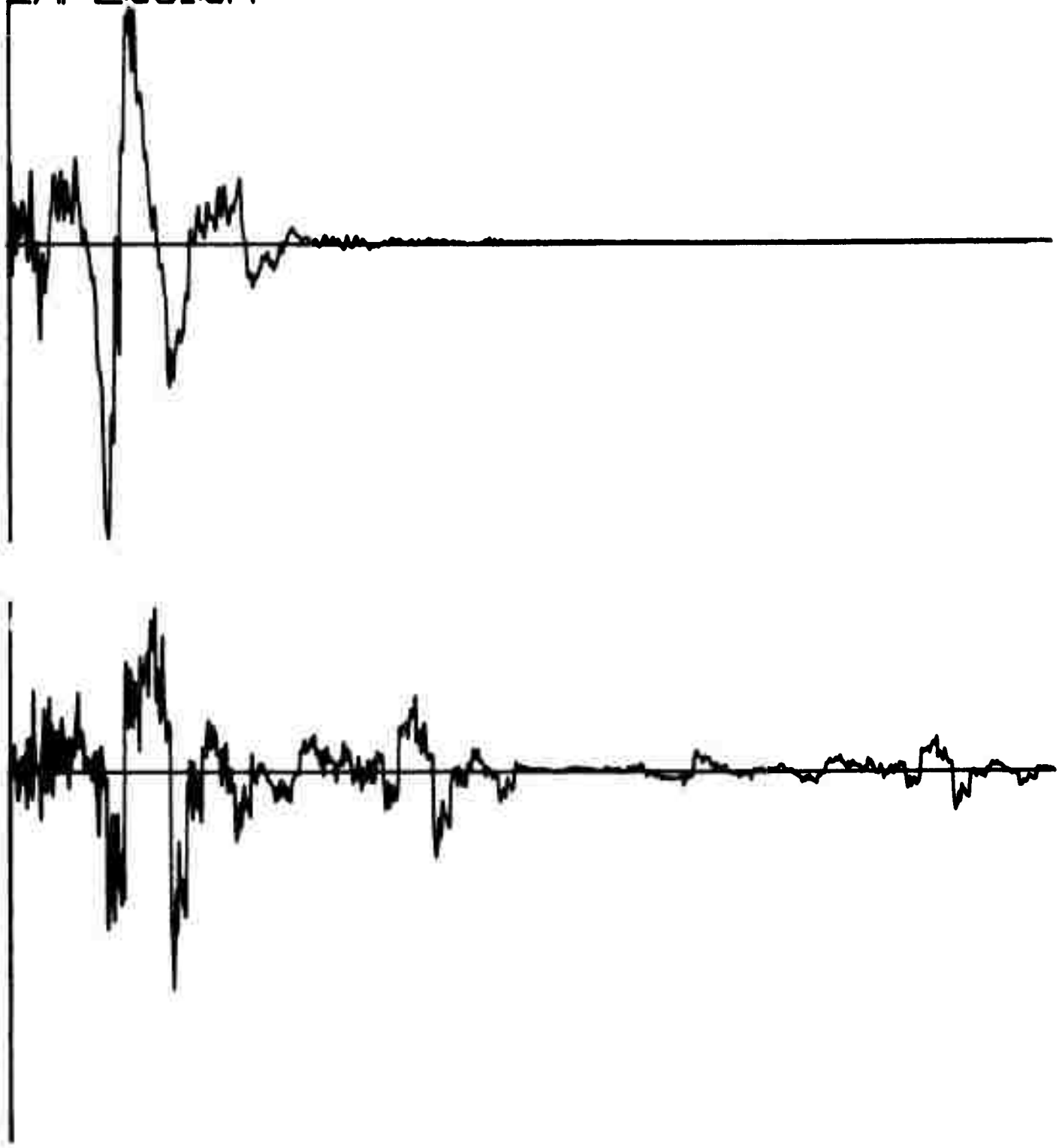
X322

EVENT NUMBER 1529
EXPLOSION



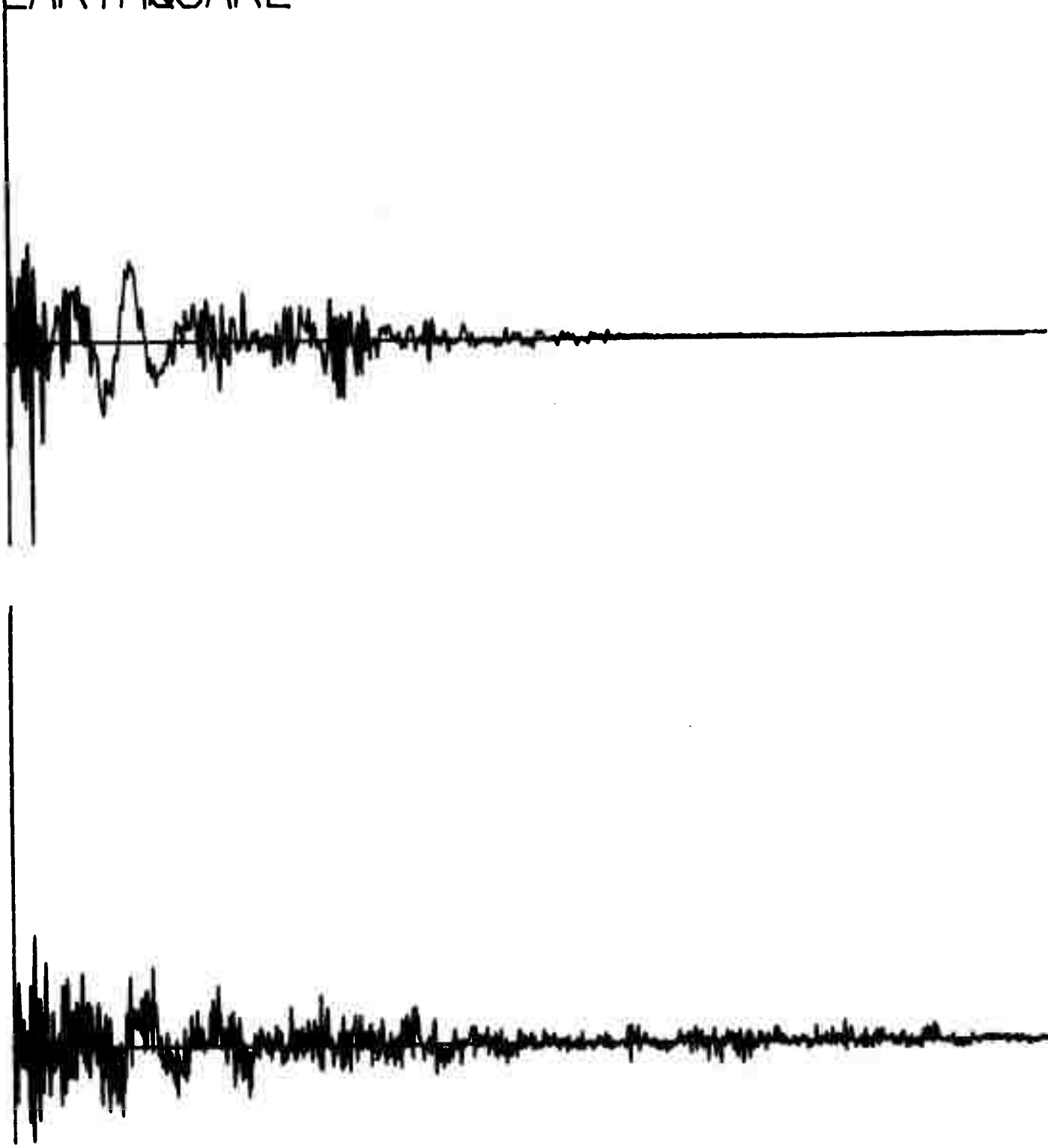
X324

EVENT NUMBER 1534
EXPLOSION

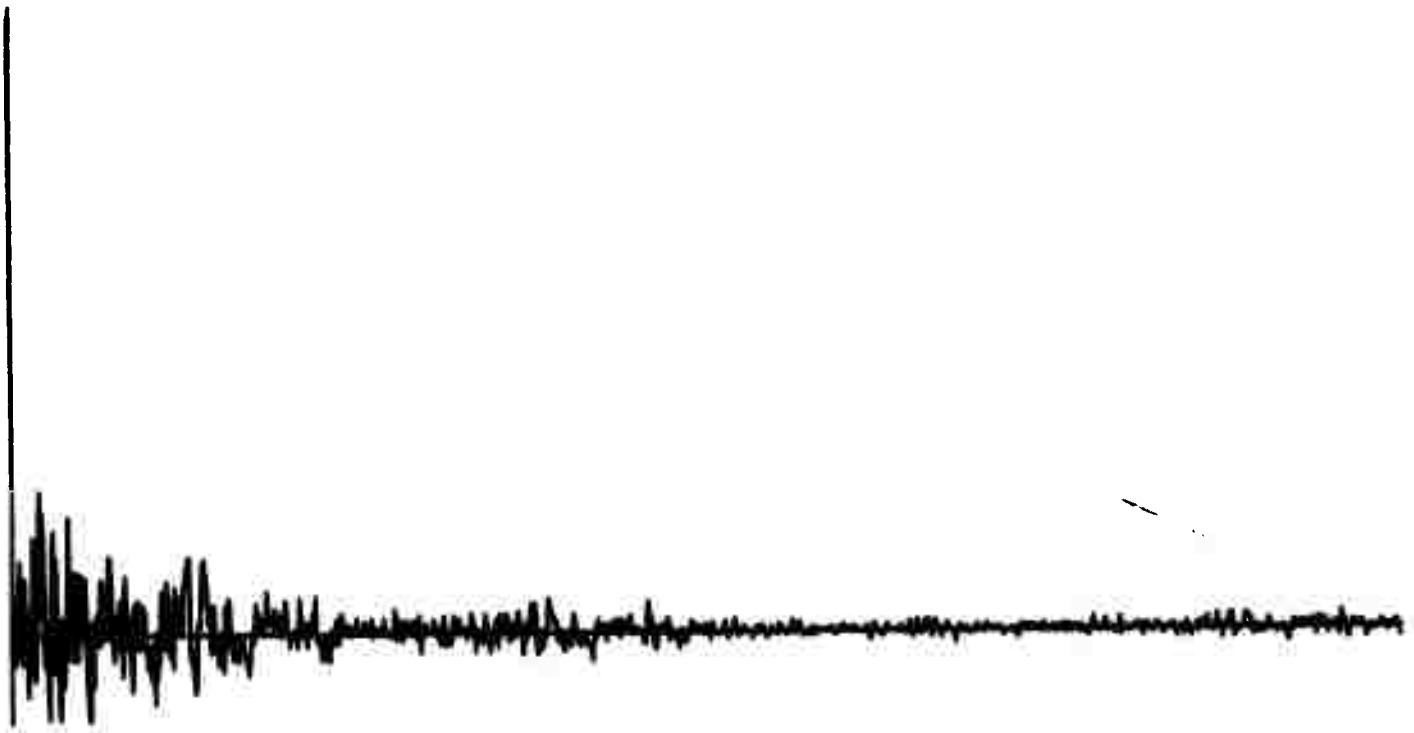


Q326

EVENT NUMBER 1313
EARTHQUAKE

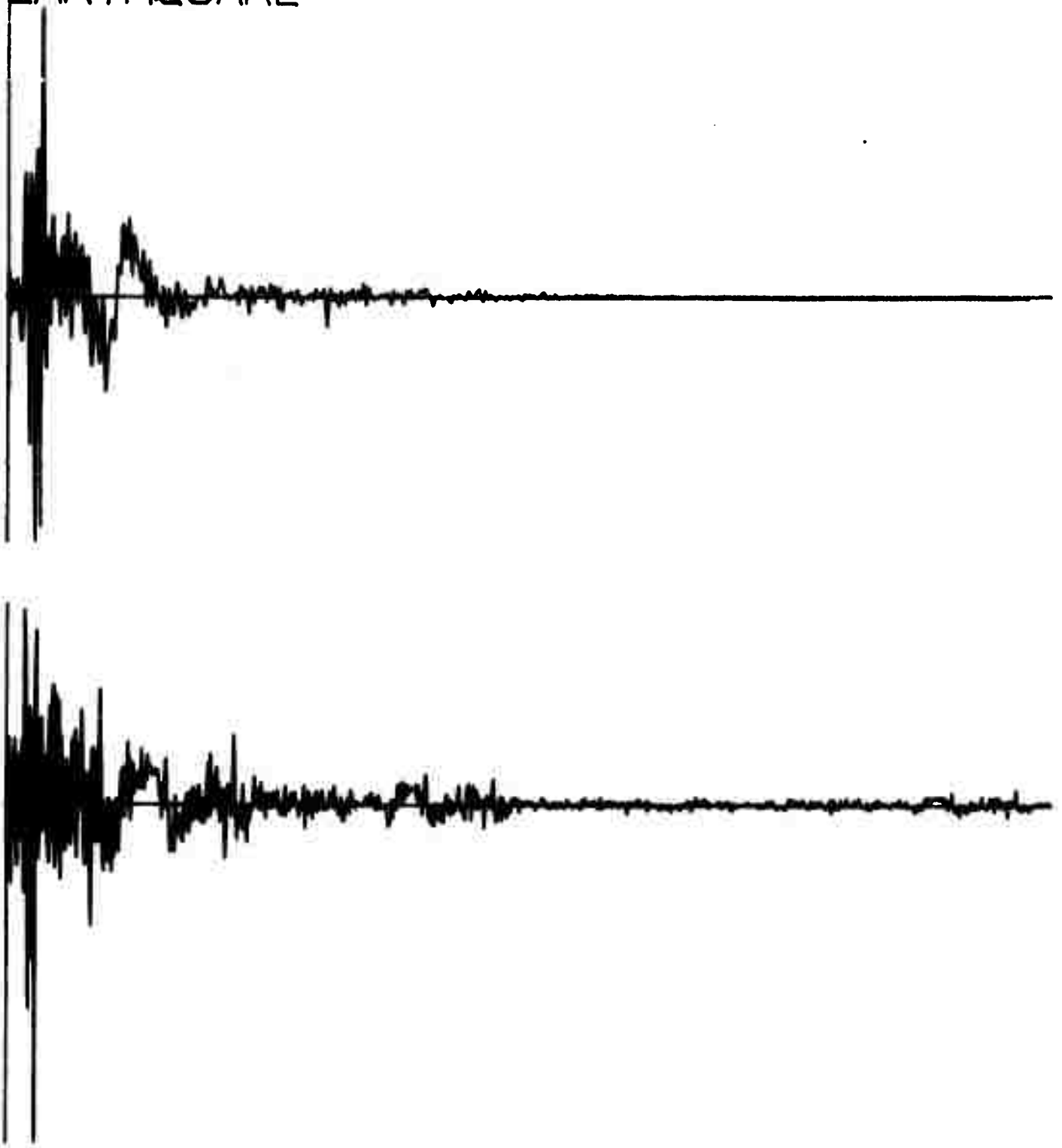


EVENT NUMBER 1314
EARTHQUAKE



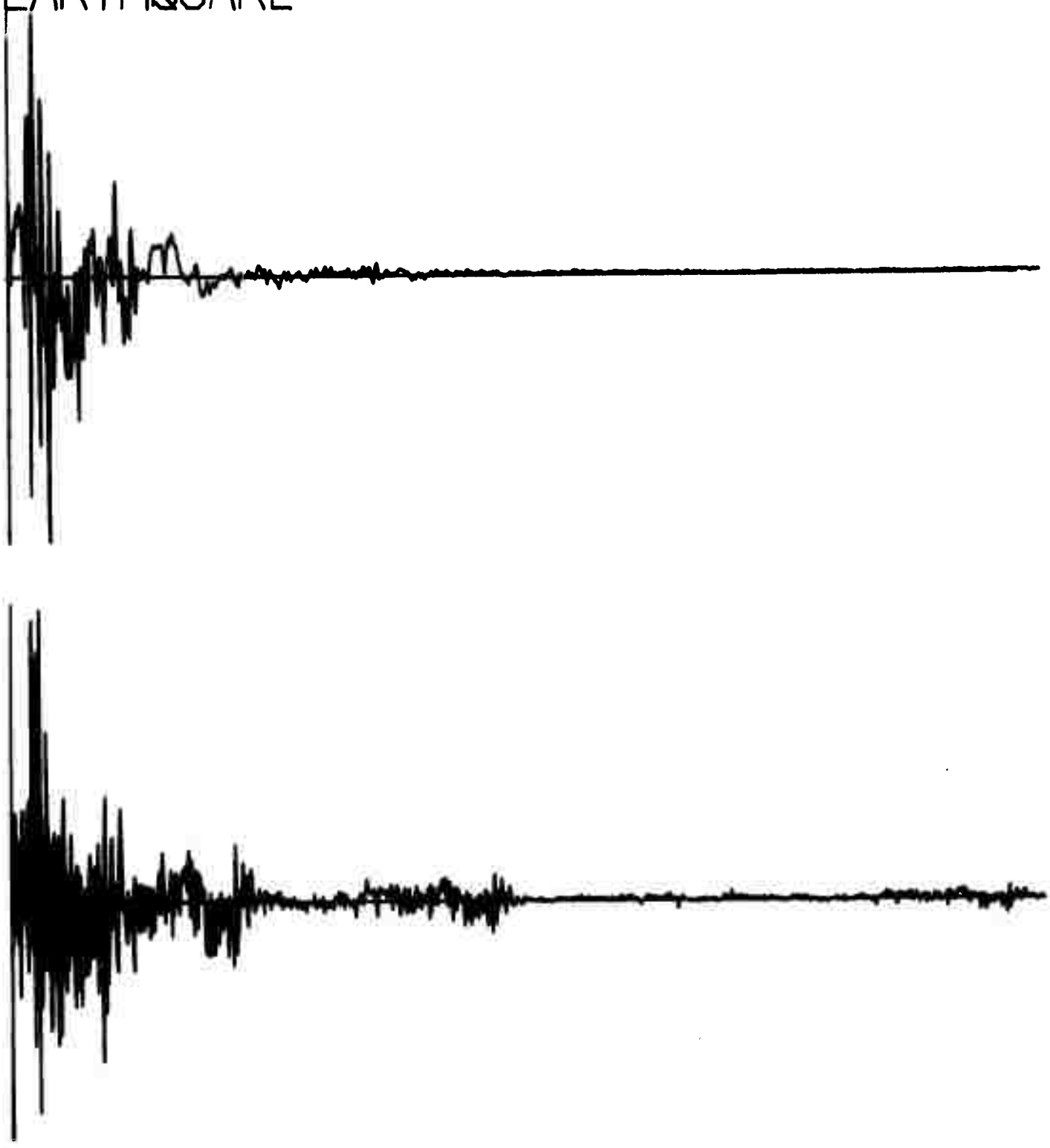
Q330

EVENT NUMBER 1316
EARTHQUAKE



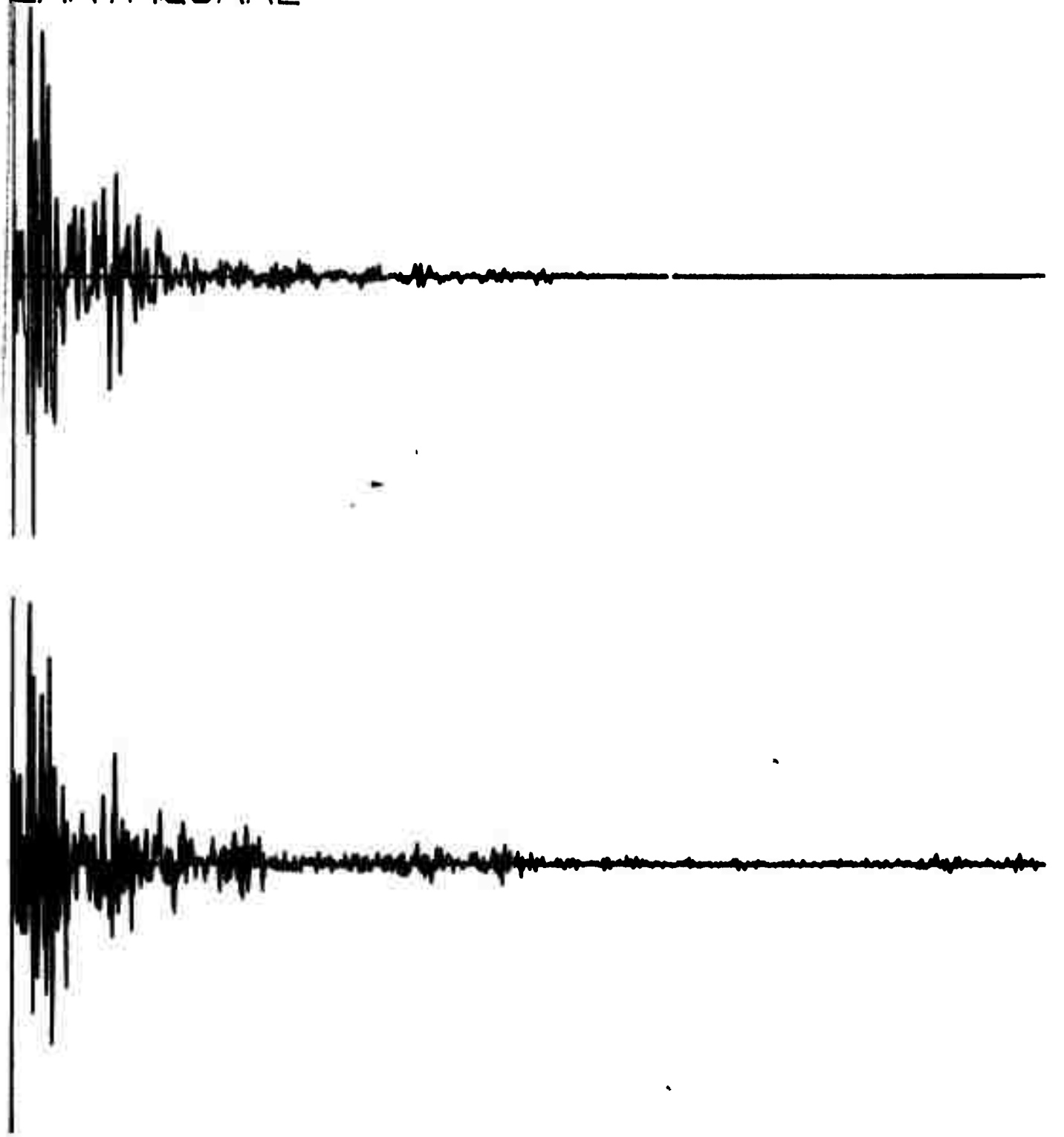
Q332

EVENT NUMBER 1318
EARTHQUAKE



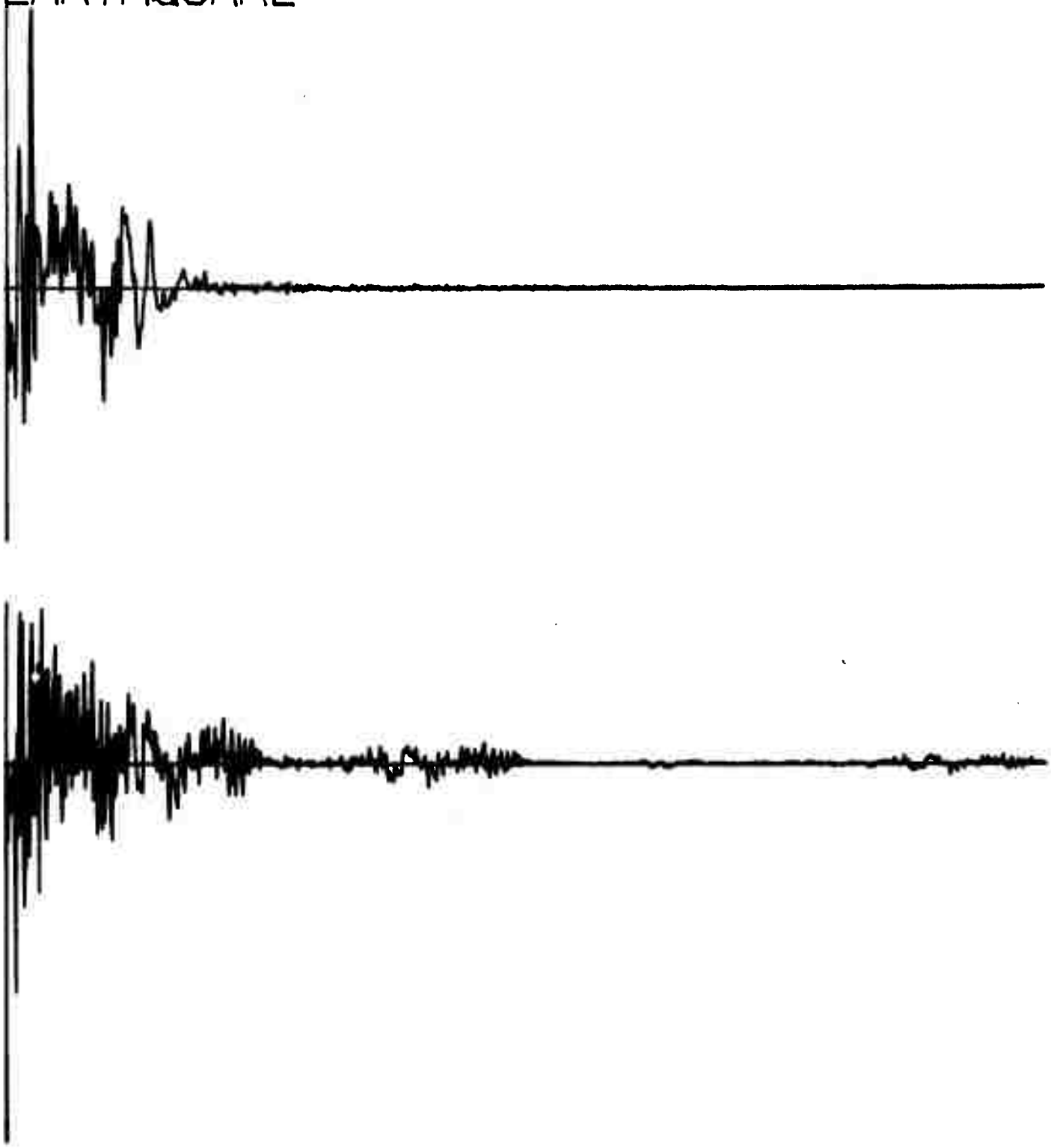
Q334

EVENT NUMBER 1319
EARTHQUAKE

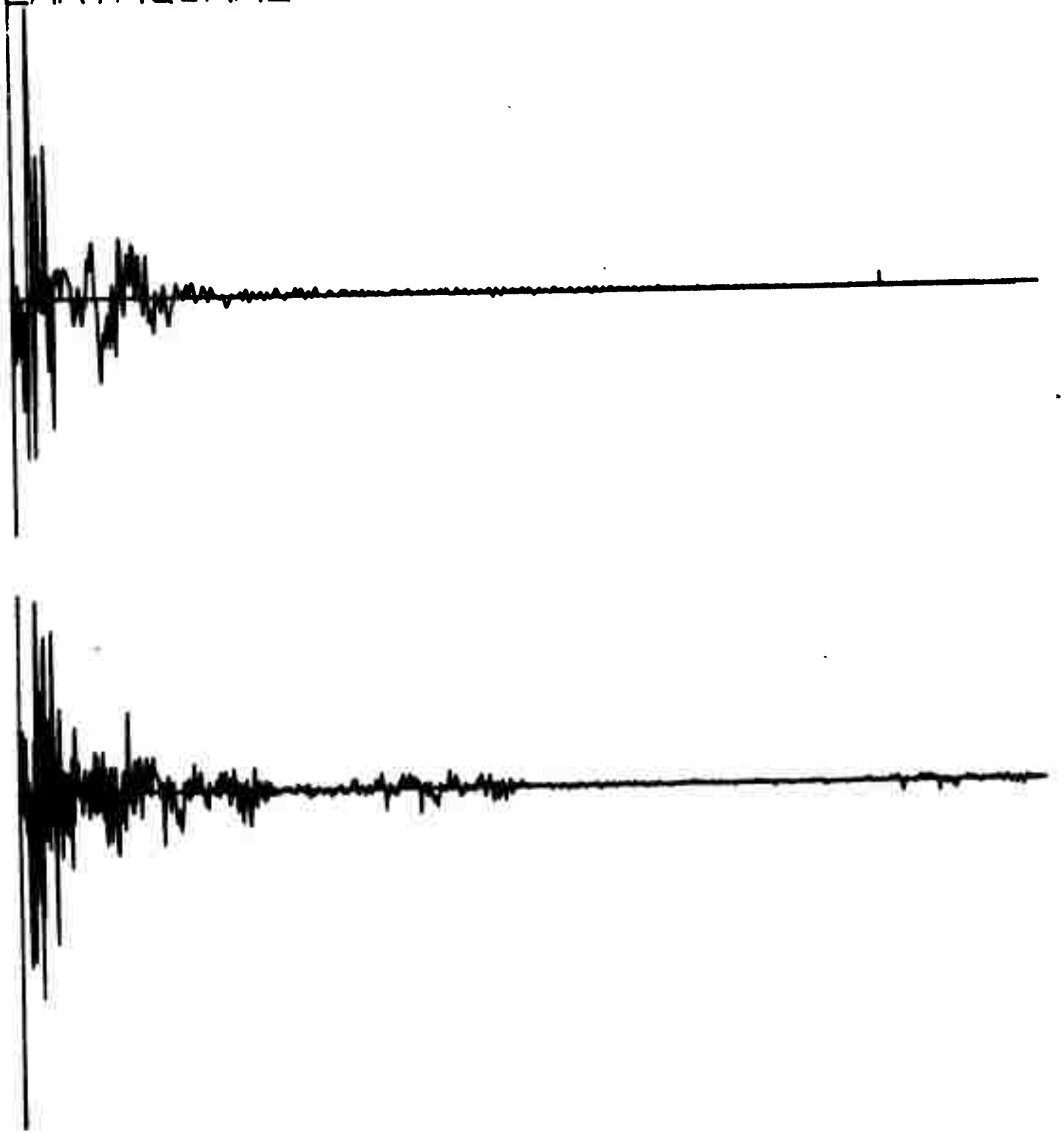


Q336

EVENT NUMBER 1320
EARTHQUAKE

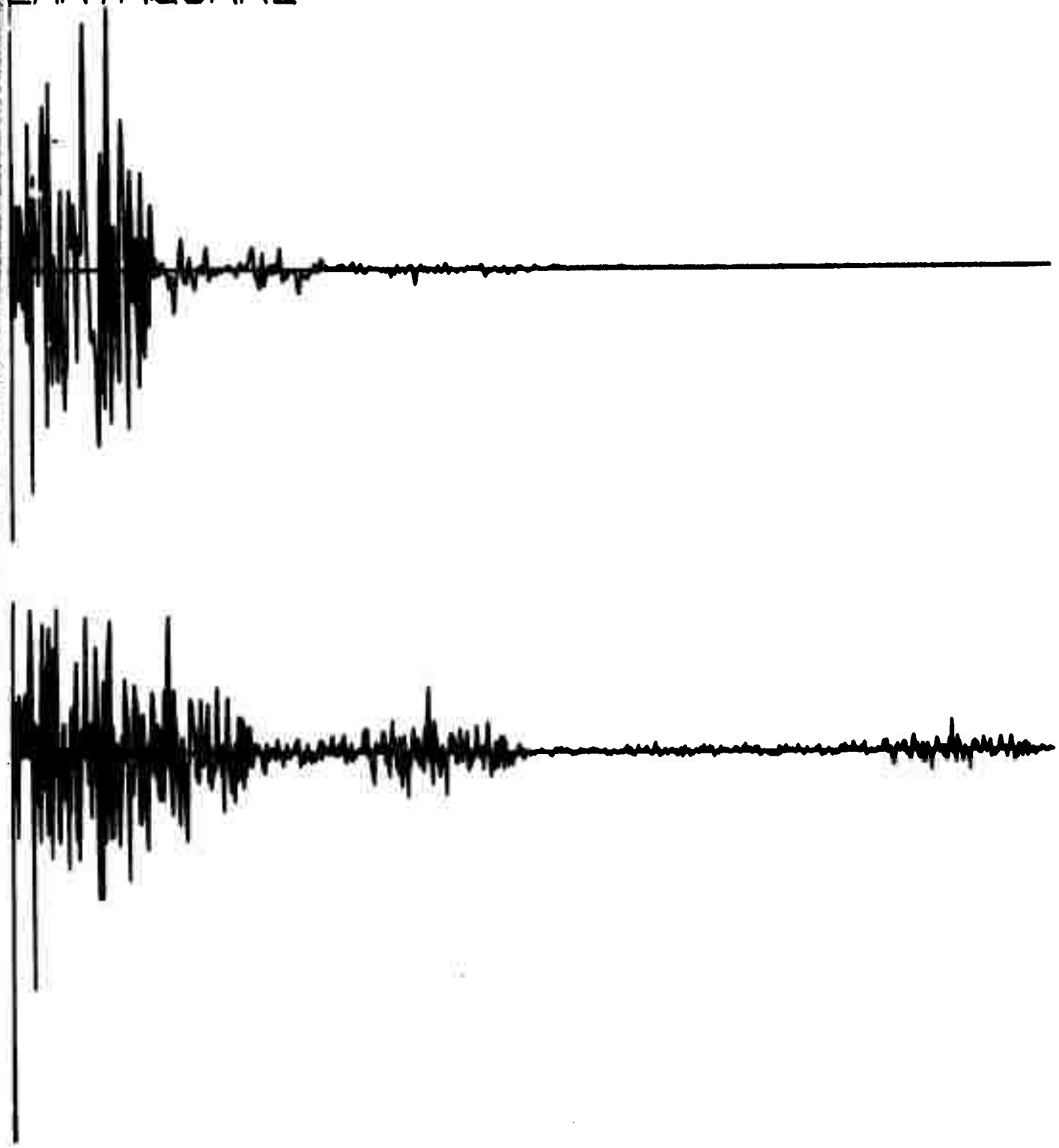


EVENT NUMBER 1321
EARTHQUAKE



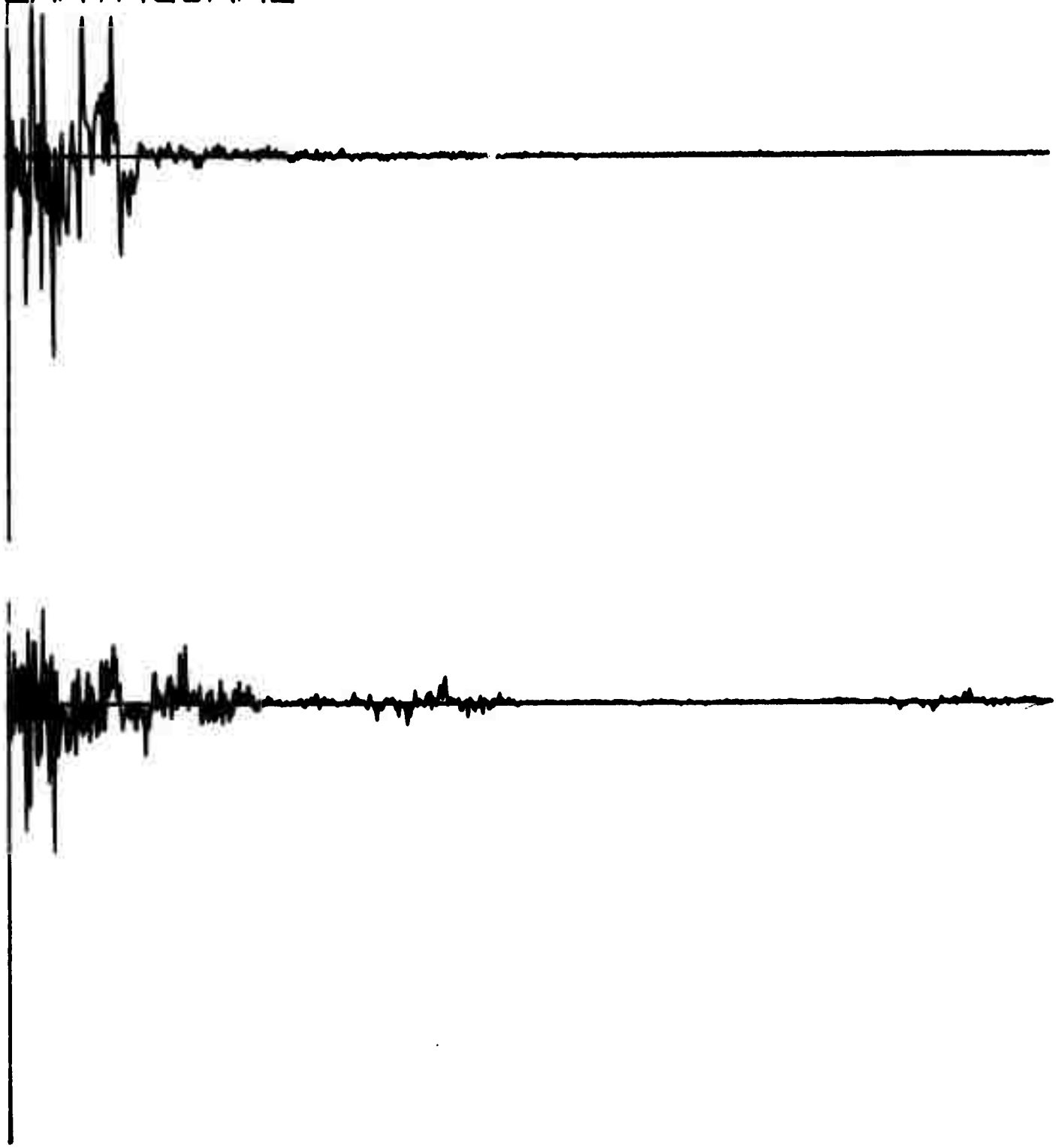
Q340

EVENT NUMBER 1322
EARTHQUAKE



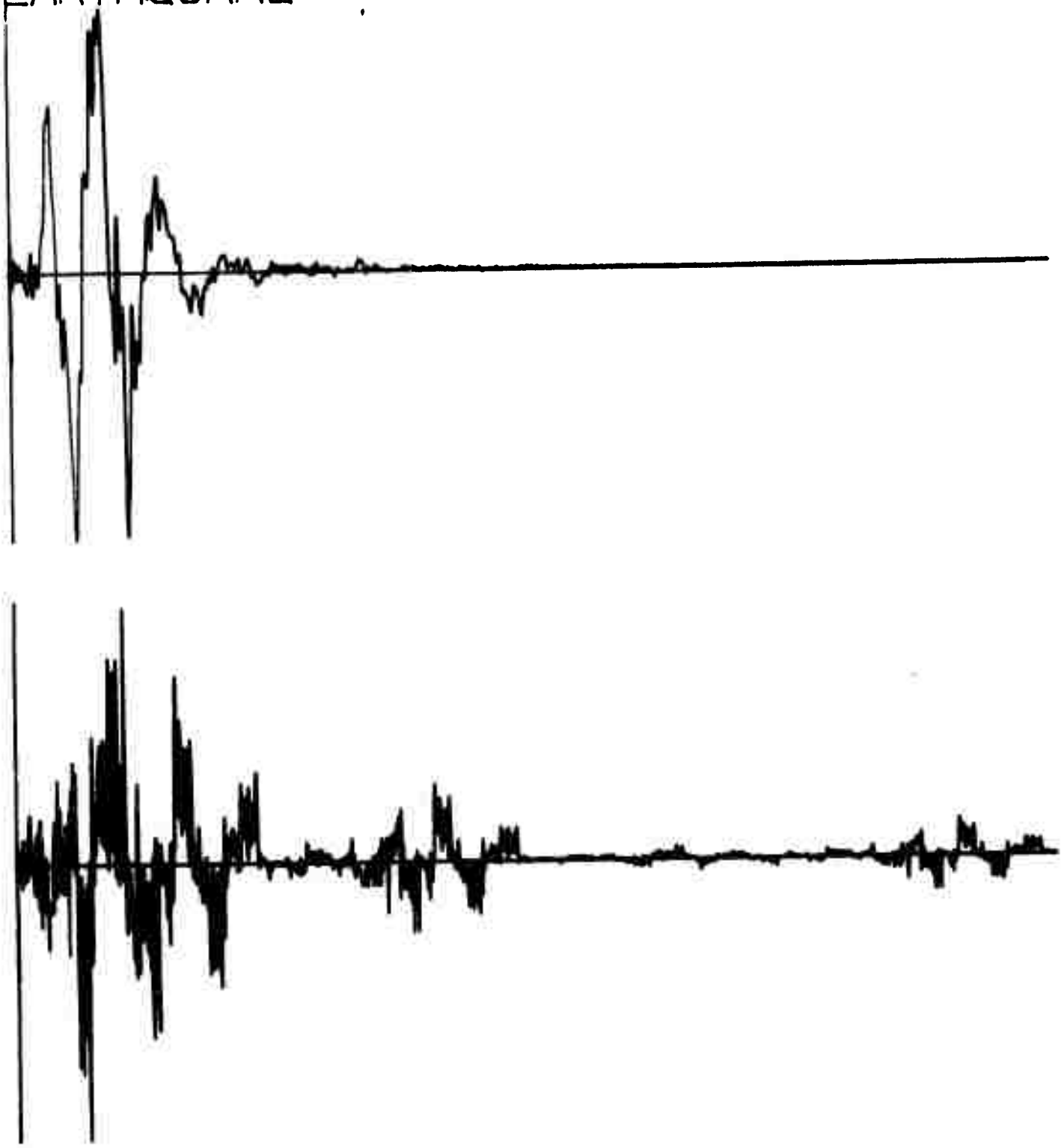
Q342

EVENT NUMBER 1275
EARTHQUAKE



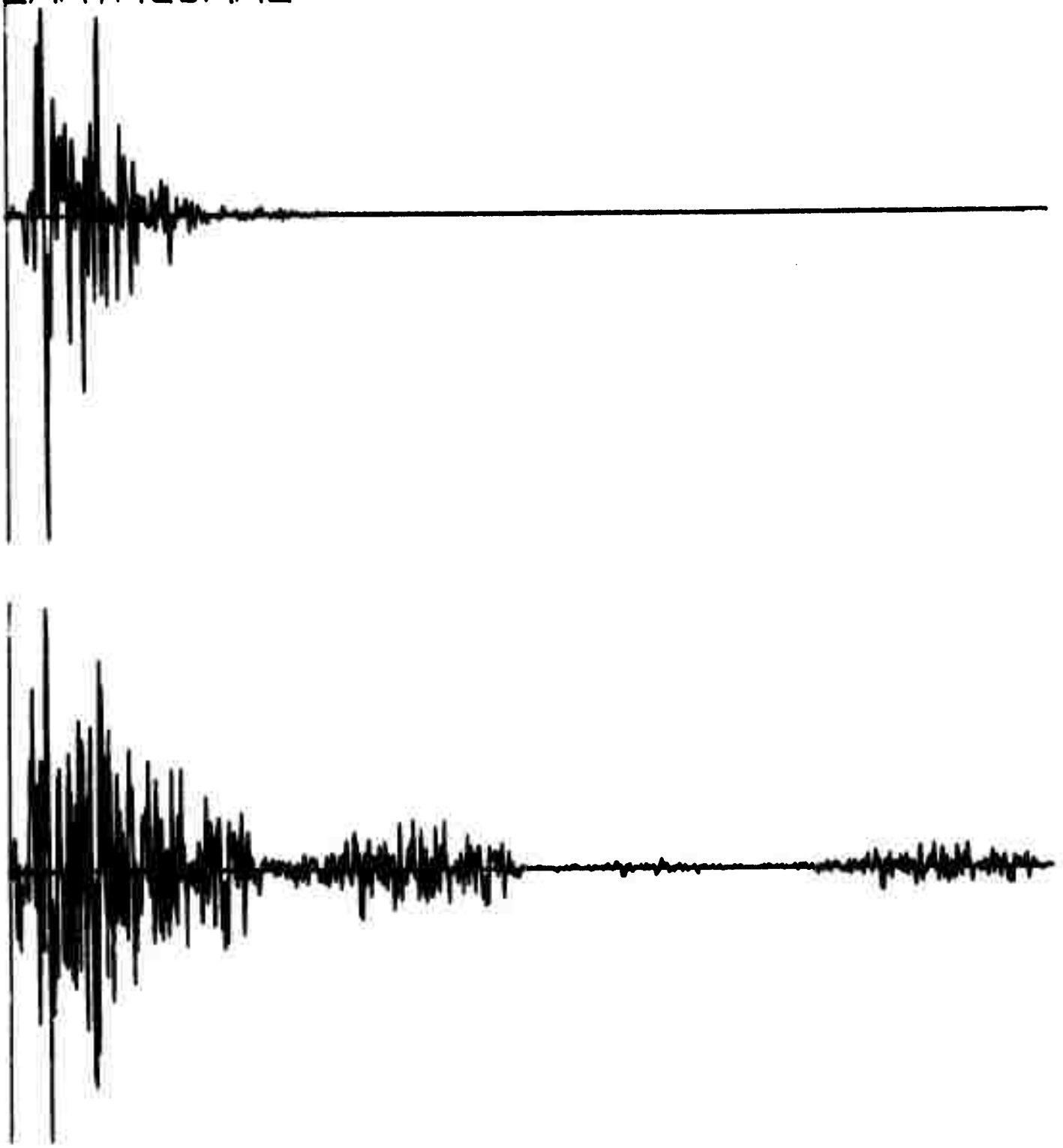
Q344

EVENT NUMBER 1278
EARTHQUAKE



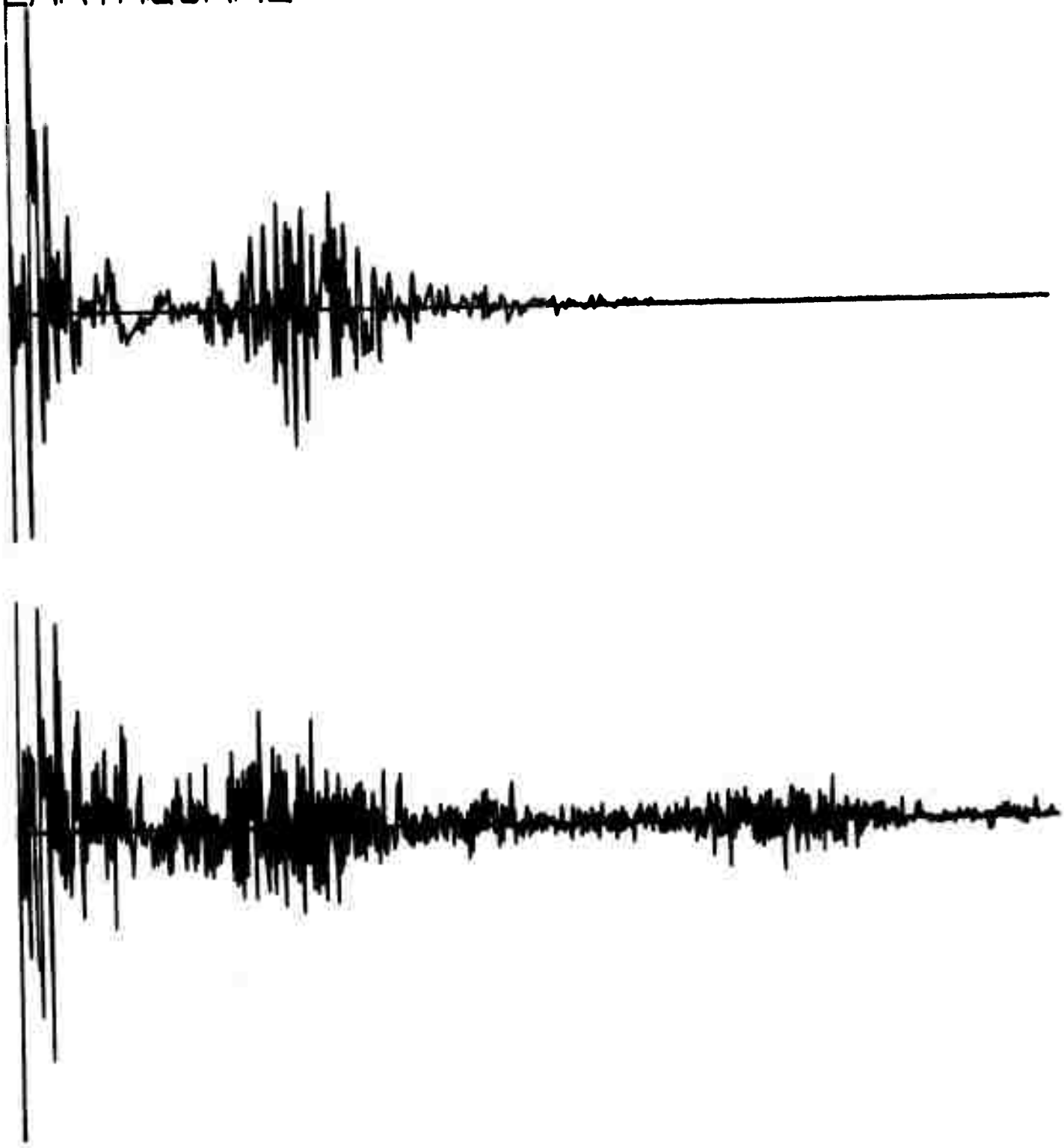
Q346

EVENT NUMBER 2000
EARTHQUAKE



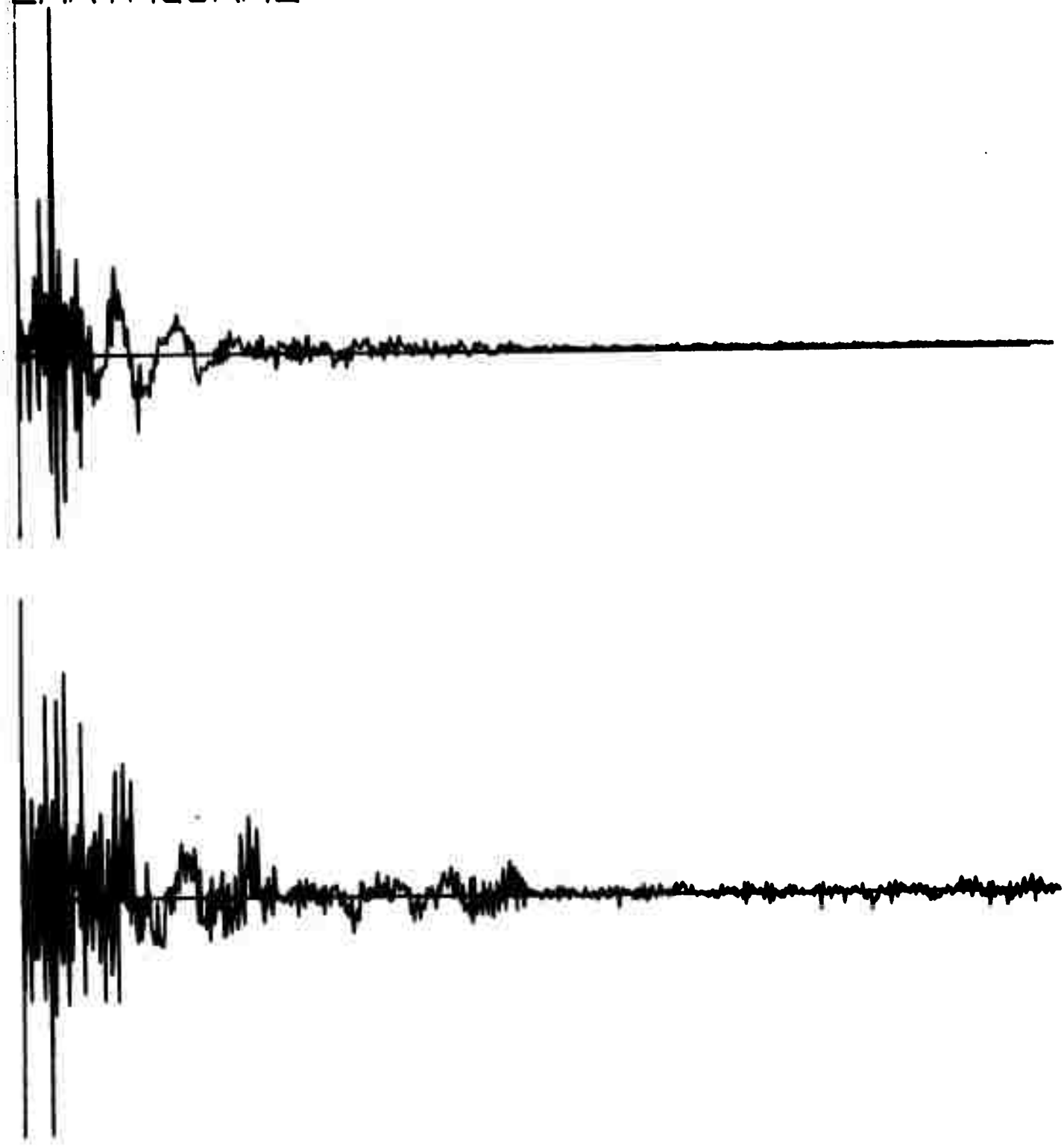
Q348

EVENT NUMBER 1058
EARTHQUAKE



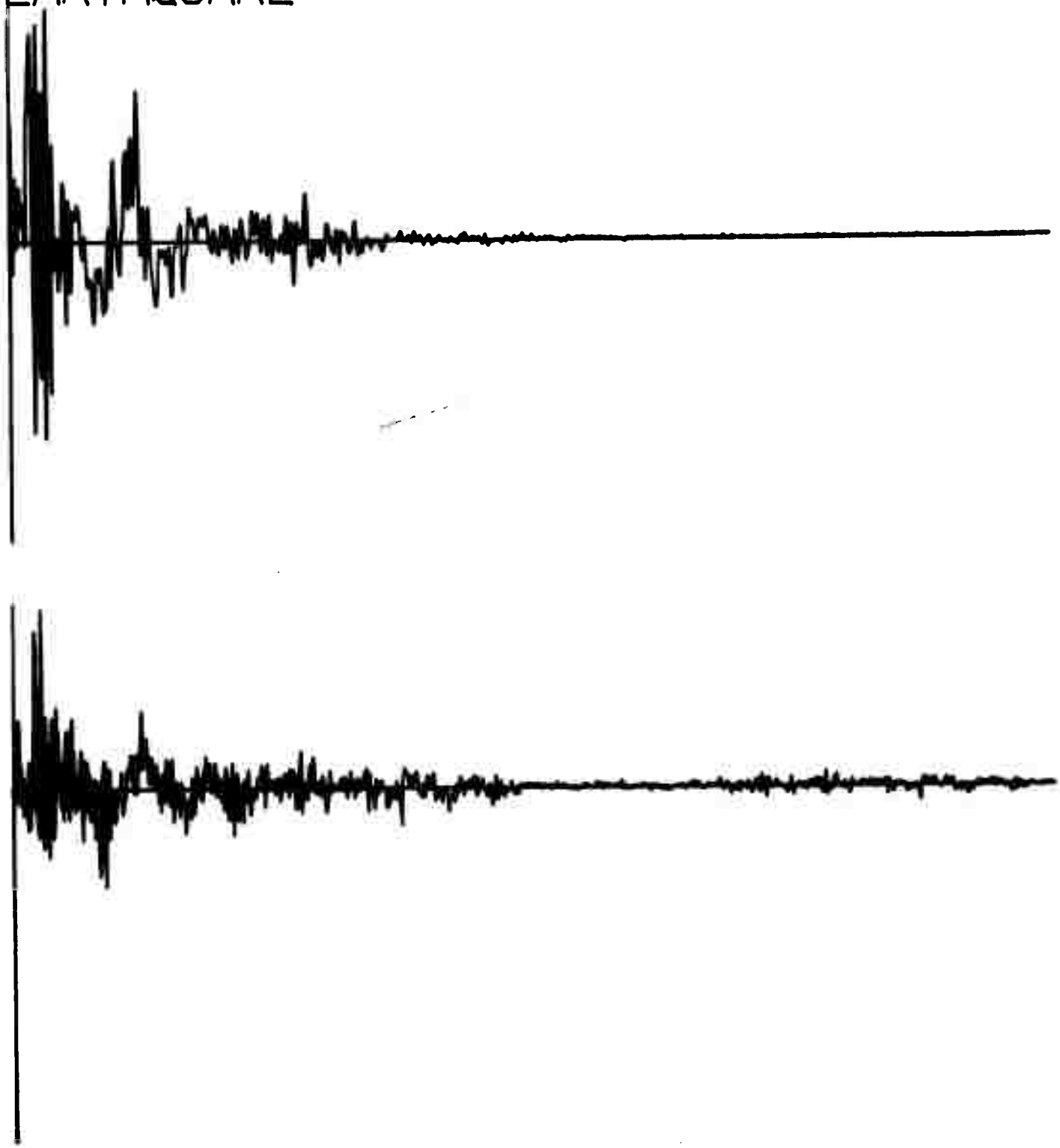
Q350

EVENT NUMBER 1311
EARTHQUAKE



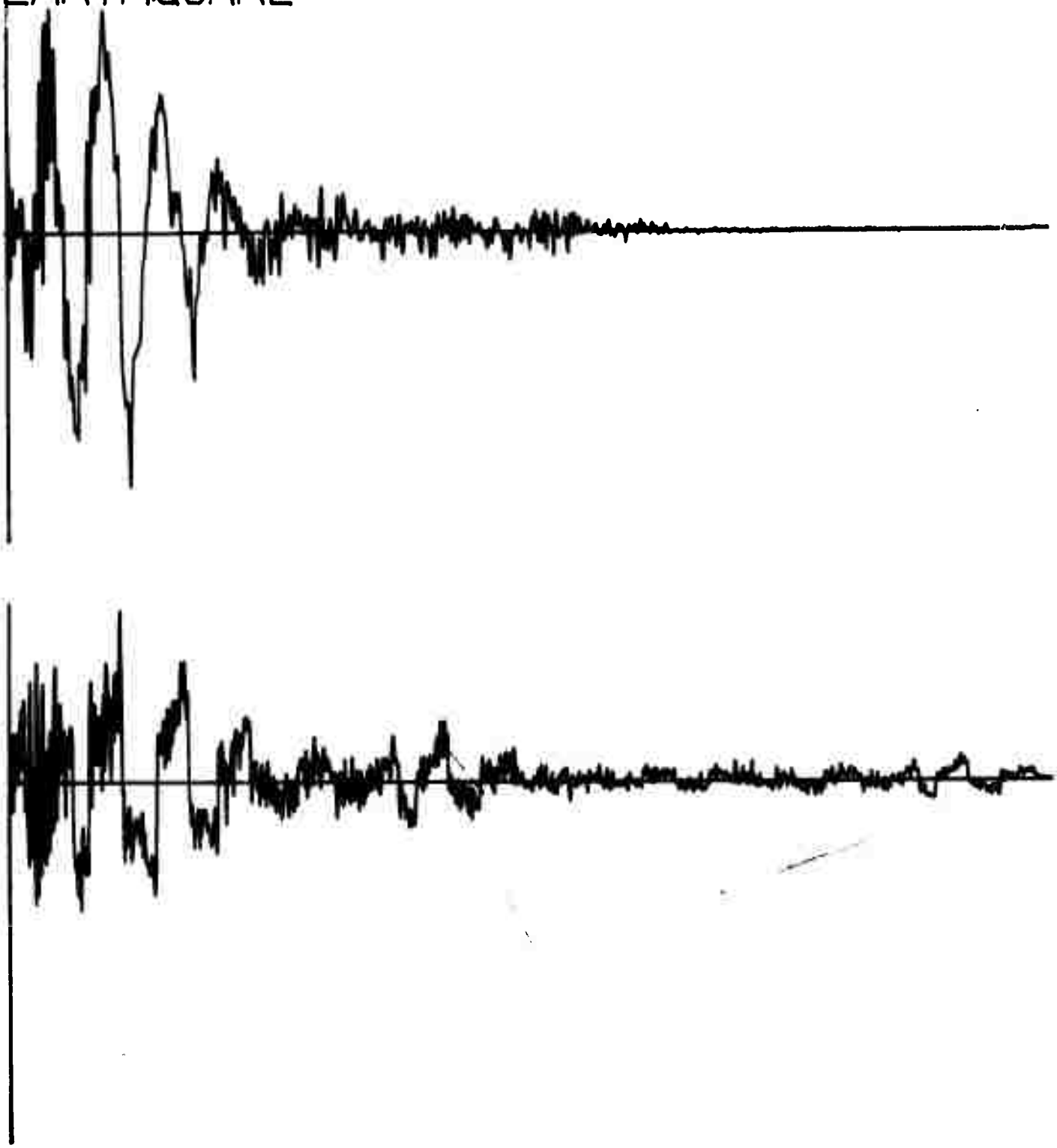
Q352

EVENT NUMBER 1307
EARTHQUAKE



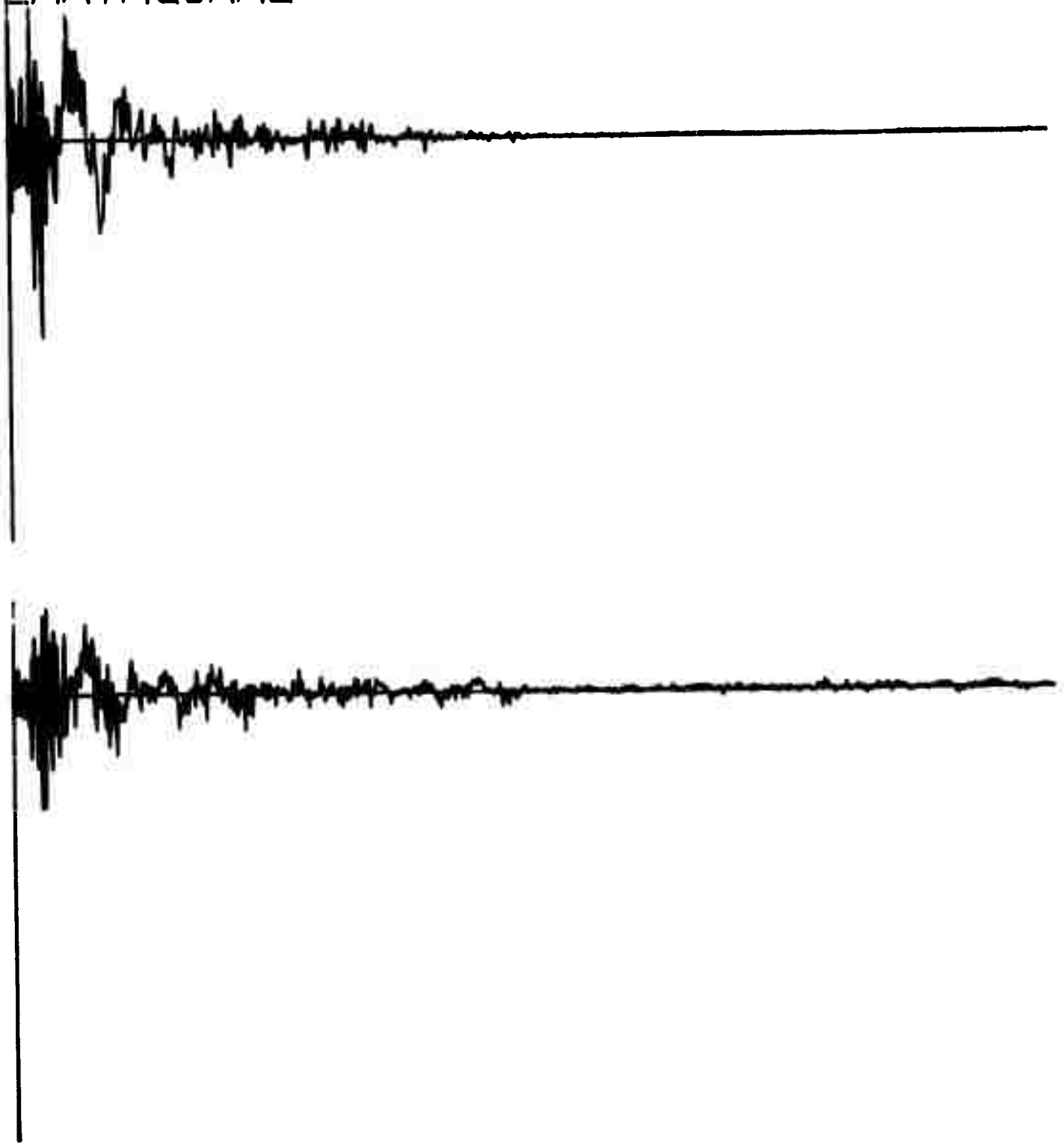
Q354

EVENT NUMBER 1306
EARTHQUAKE



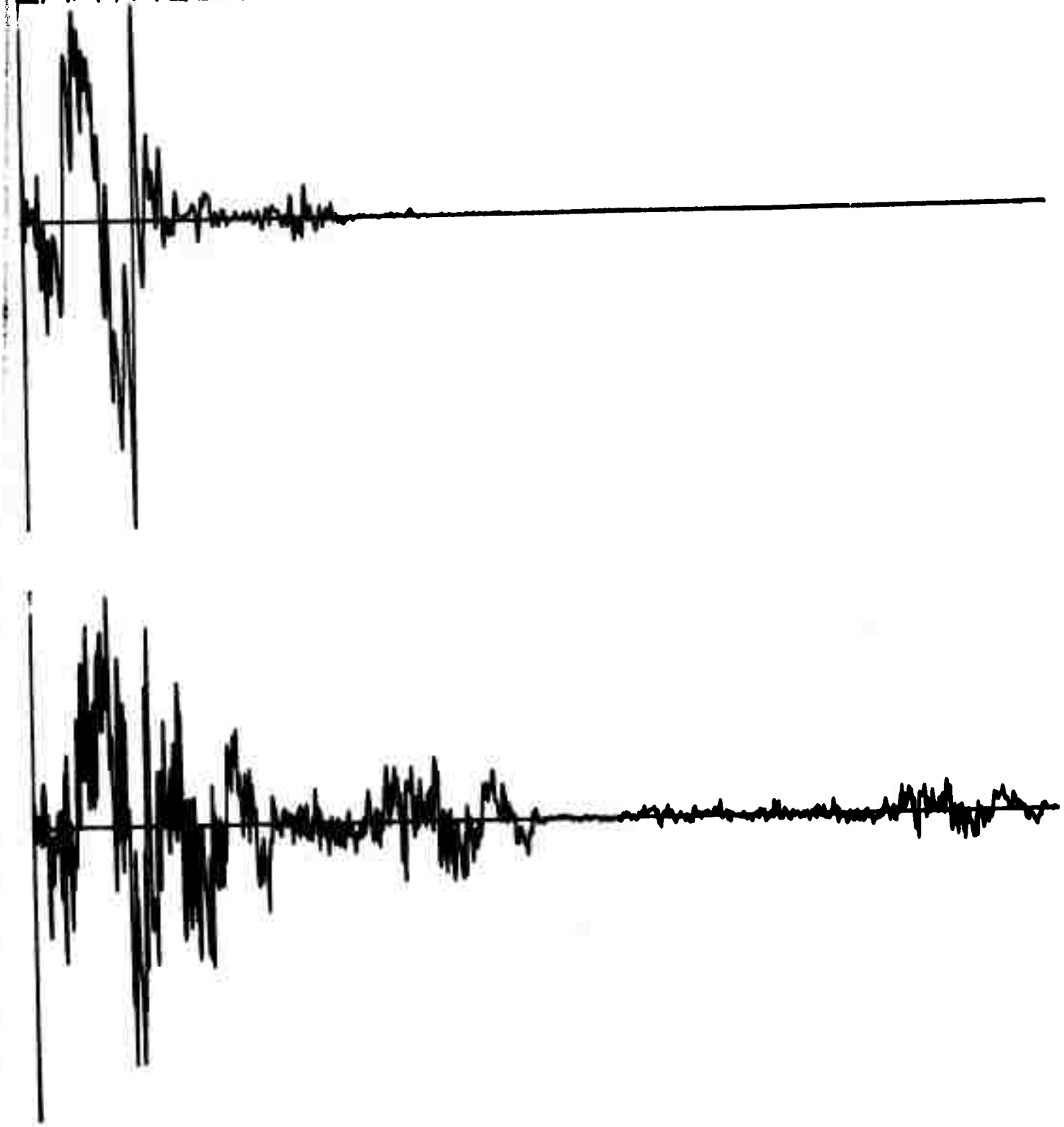
Q356

EVENT NUMBER 1276
EARTHQUAKE



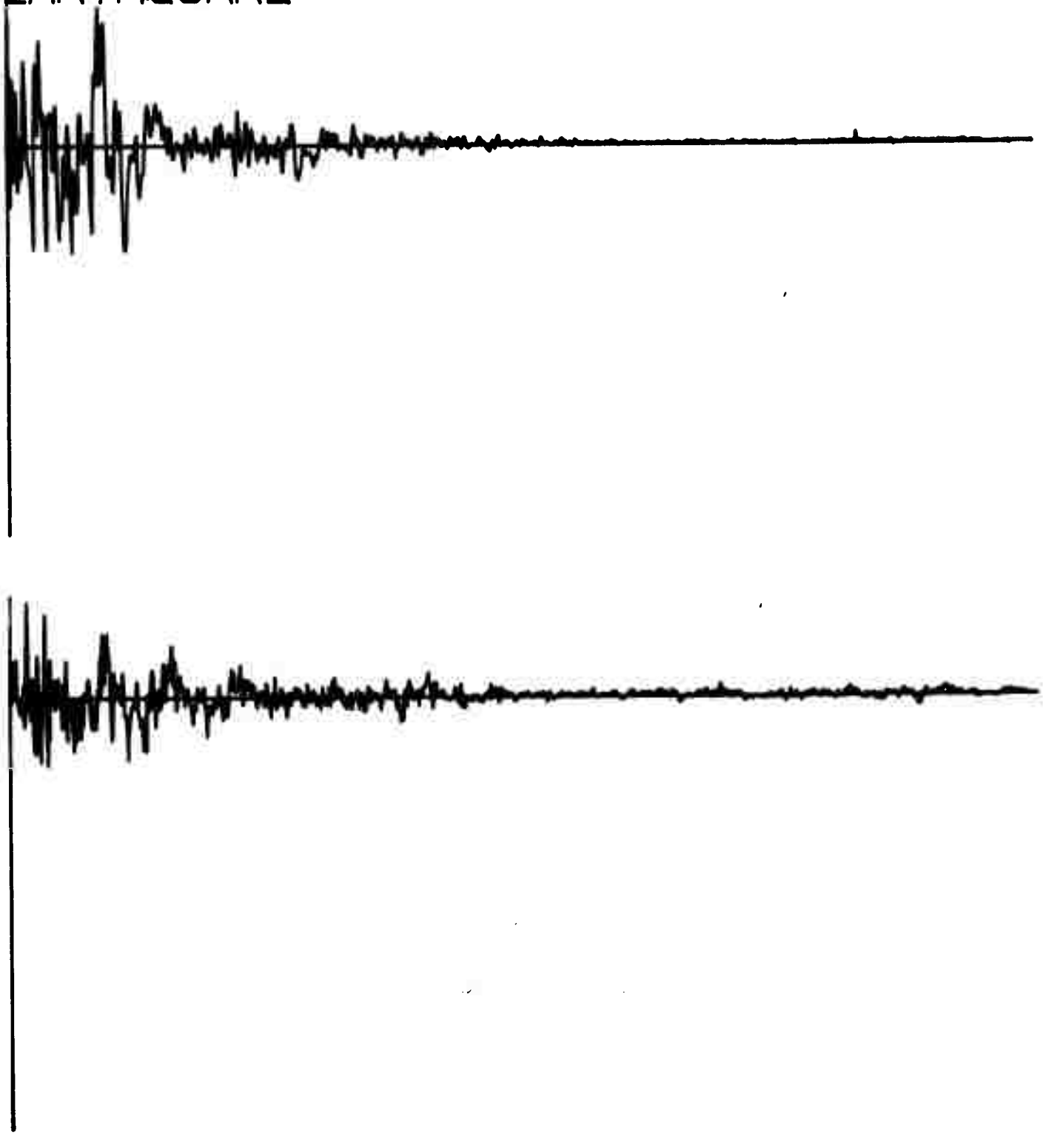
Q358

EVENT NUMBER 1277
EARTHQUAKE



Q360

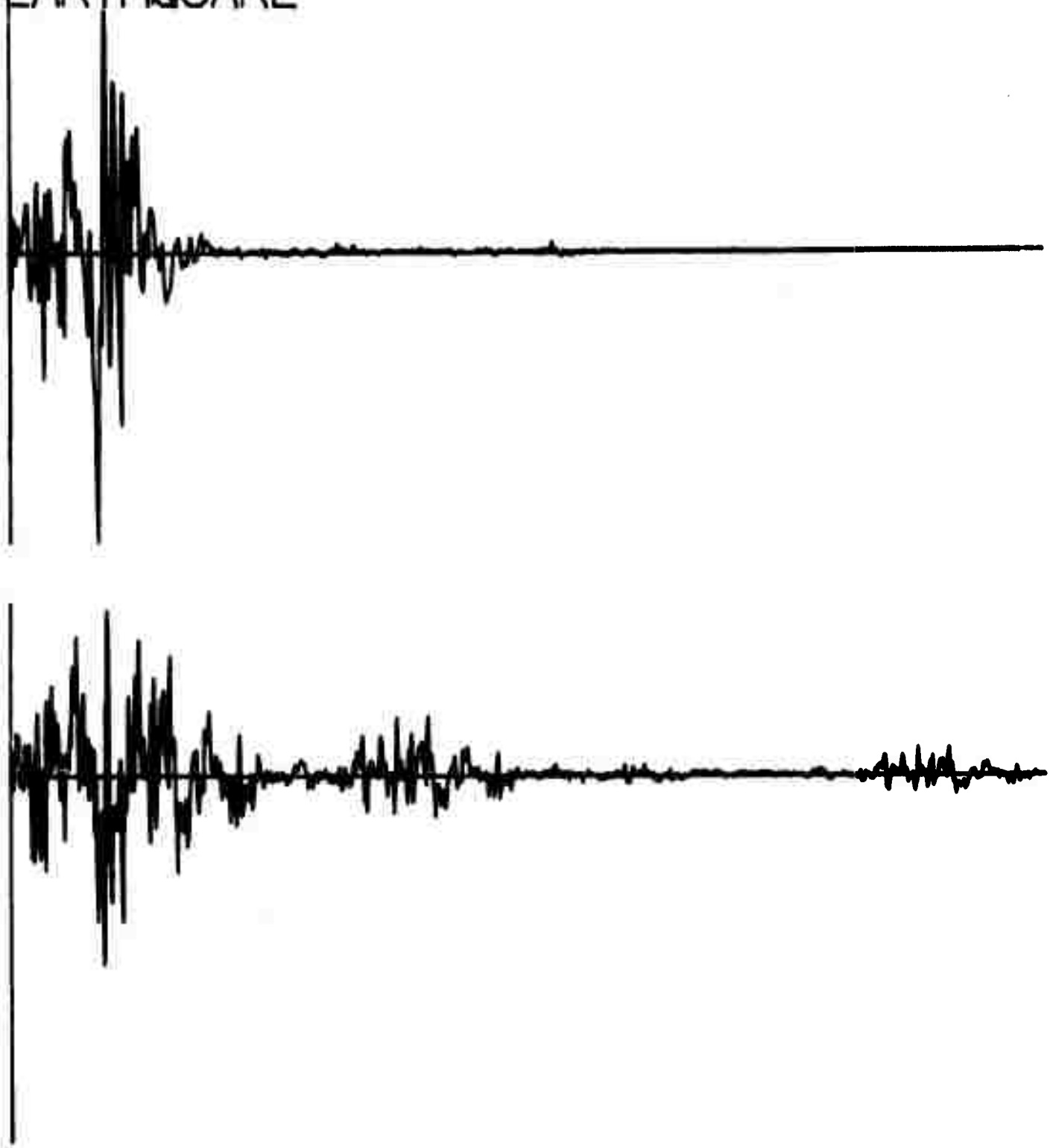
EVENT NUMBER 1324
EARTHQUAKE



362
Q101

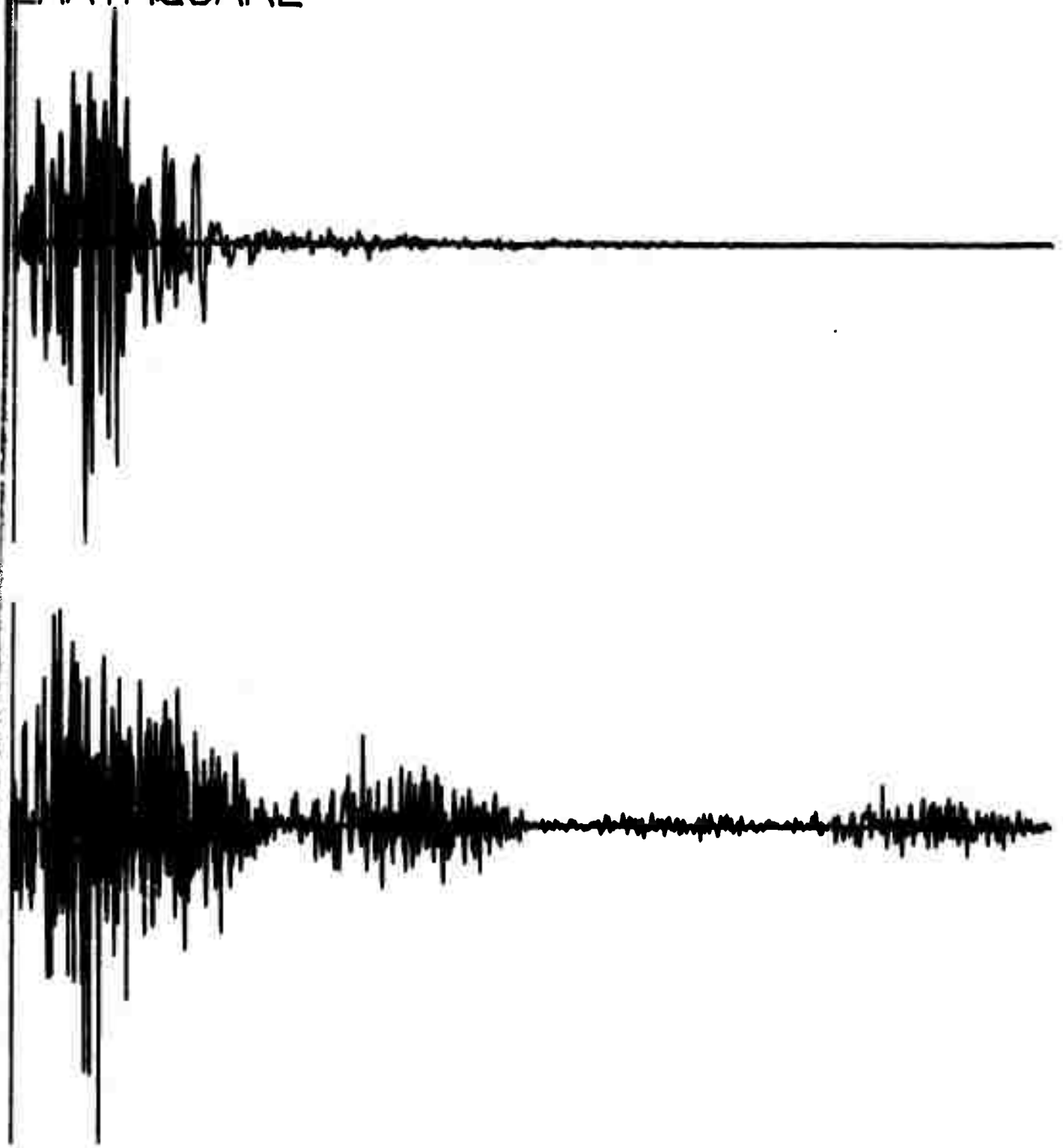
EVENT NUMBER 1325

EARTHQUAKE

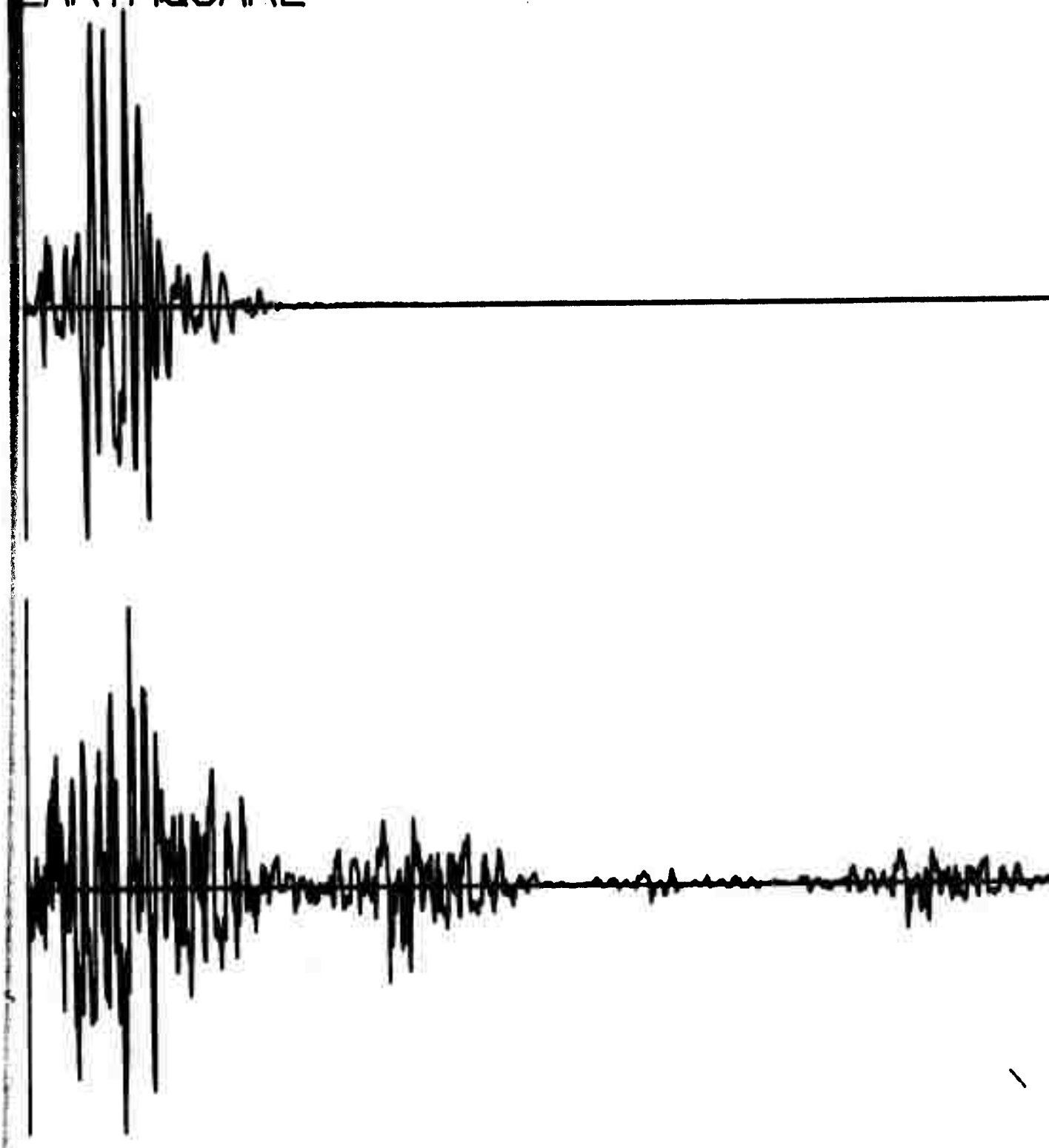


364
Q102

EVENT NUMBER 1326
EARTHQUAKE

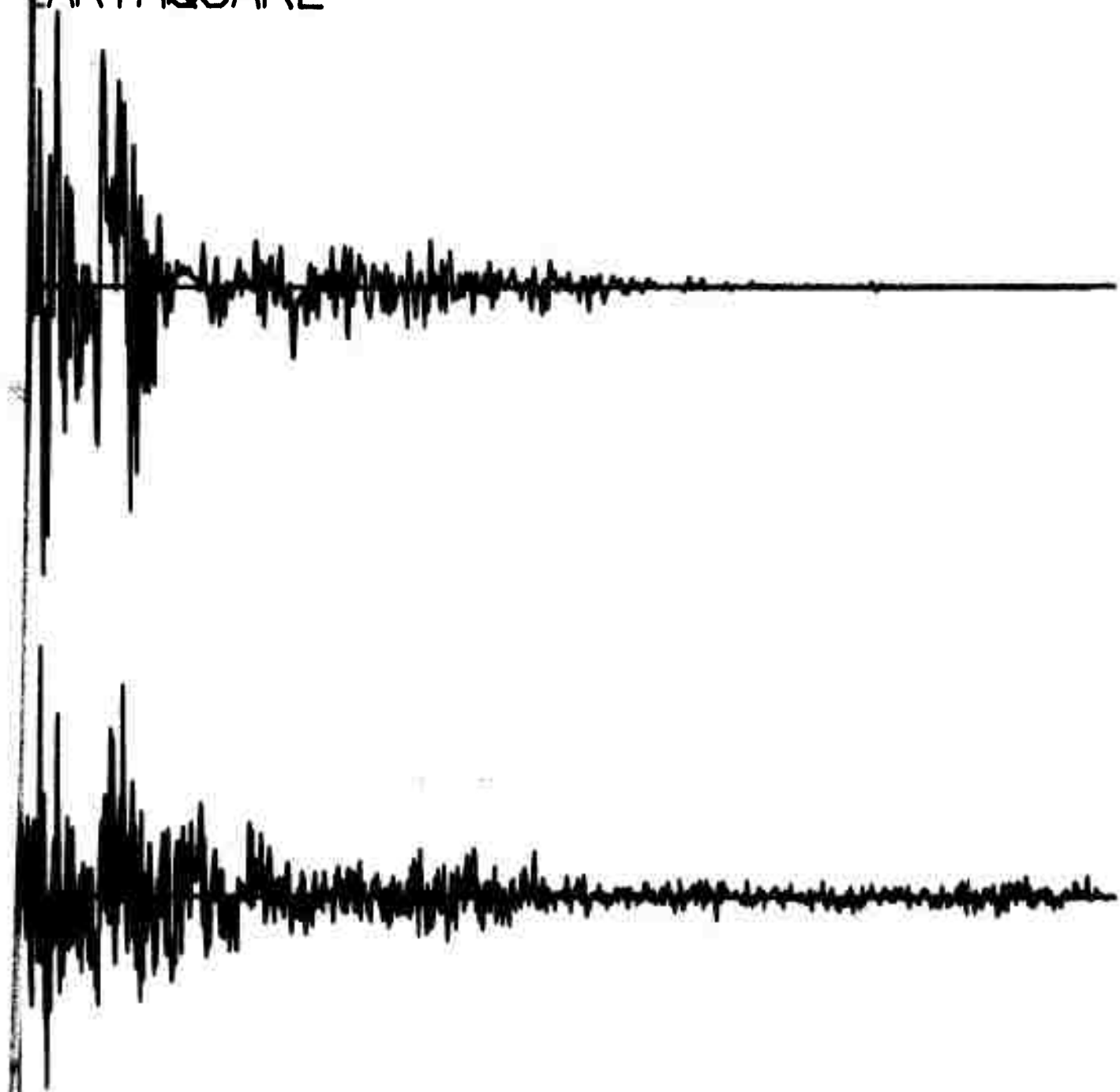


EVENT NUMBER 1328
EARTHQUAKE



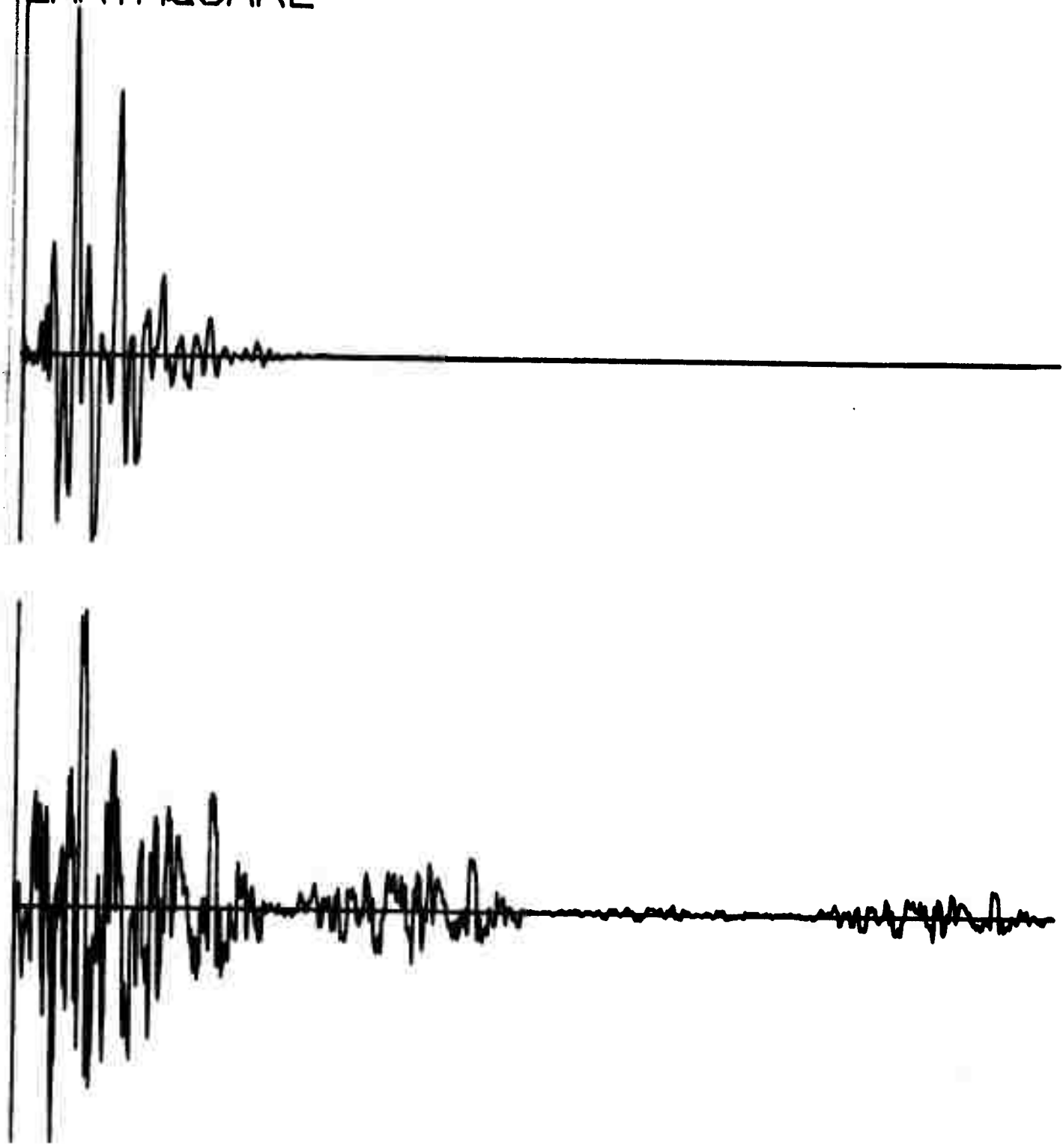
368
Q184

EVENT NUMBER 1329
EARTHQUAKE

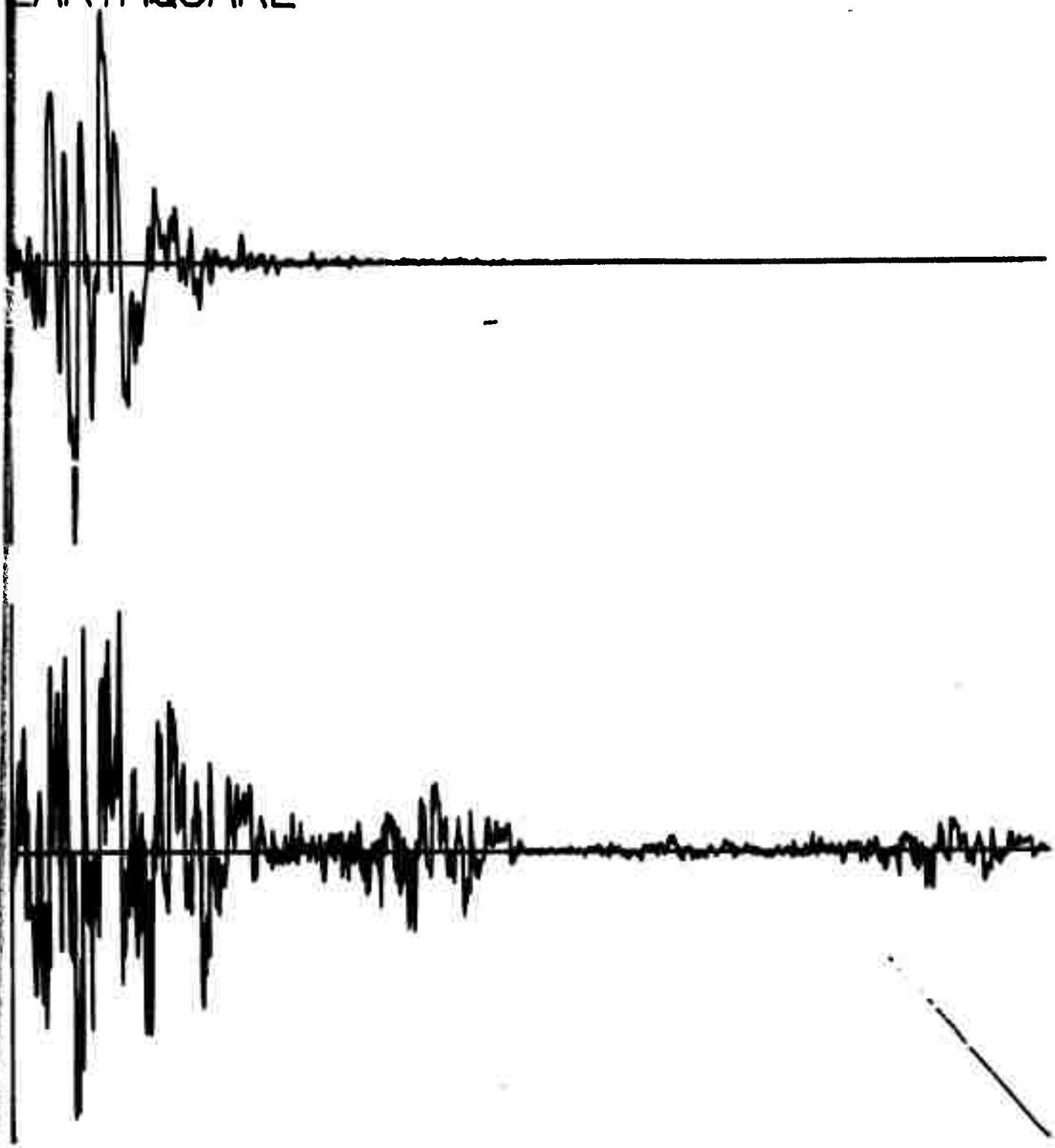


370
Q~~185~~

EVENT NUMBER 1330
EARTHQUAKE

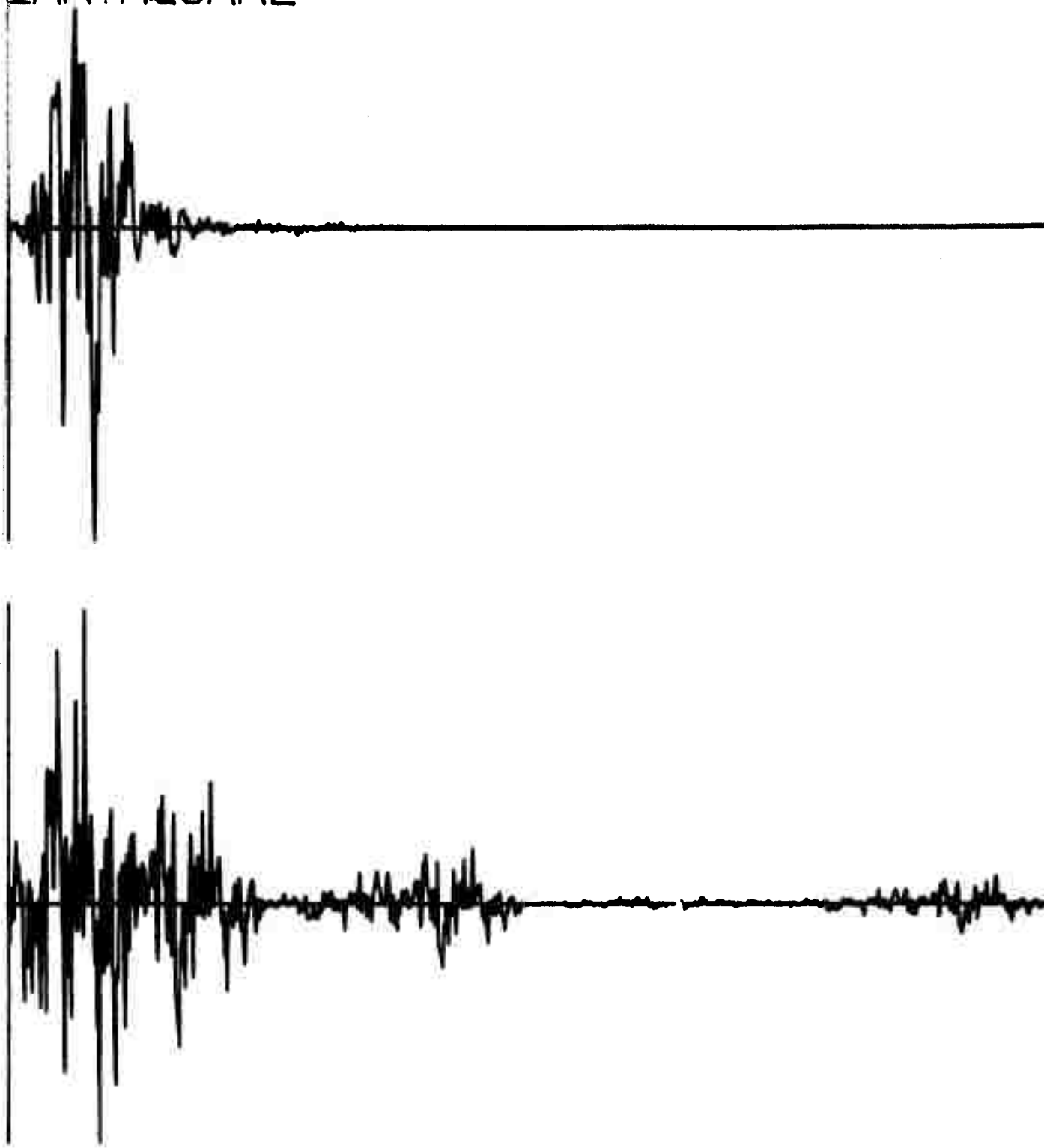


EVENT NUMBER 1331
EARTHQUAKE

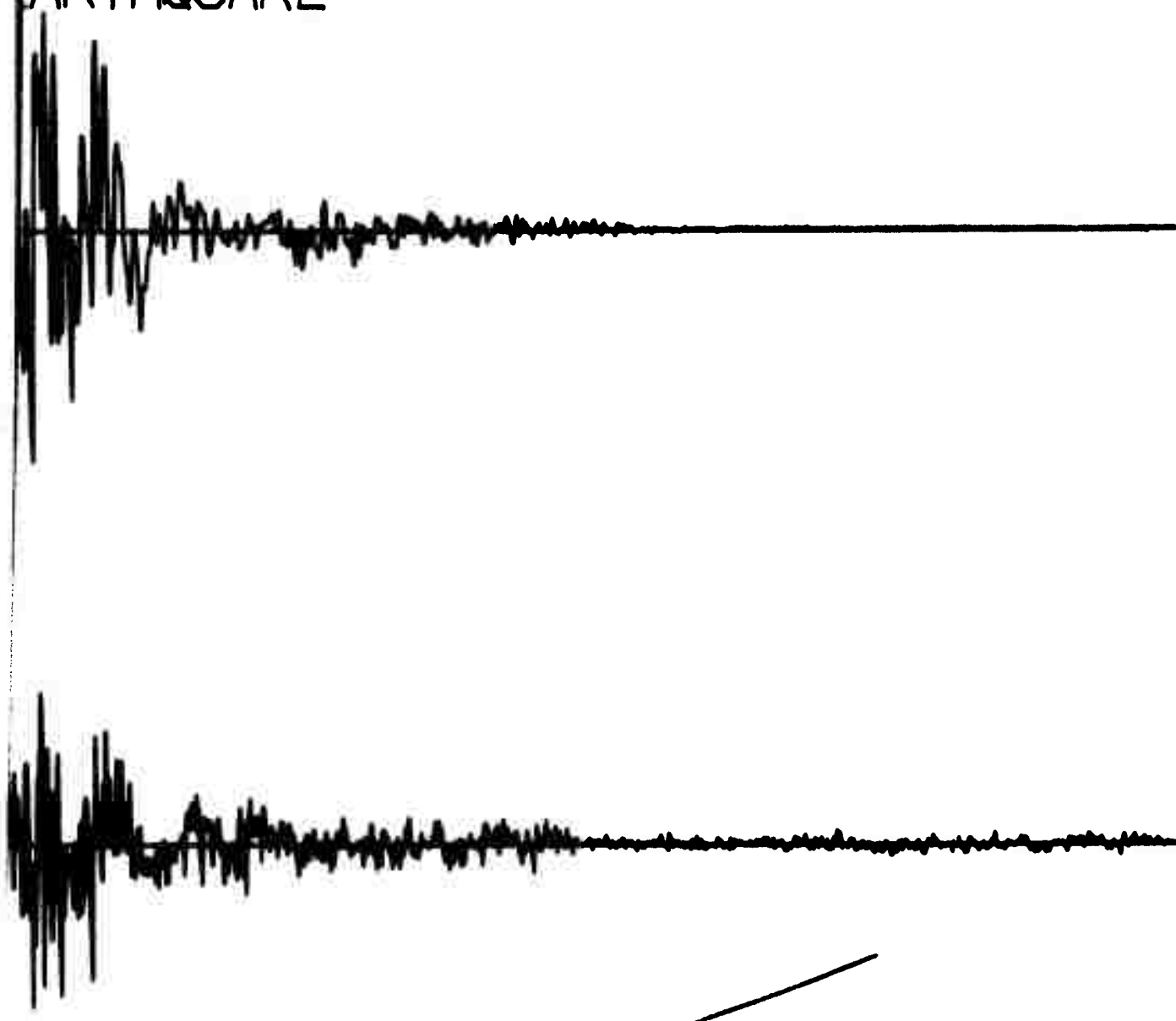


374
Q187

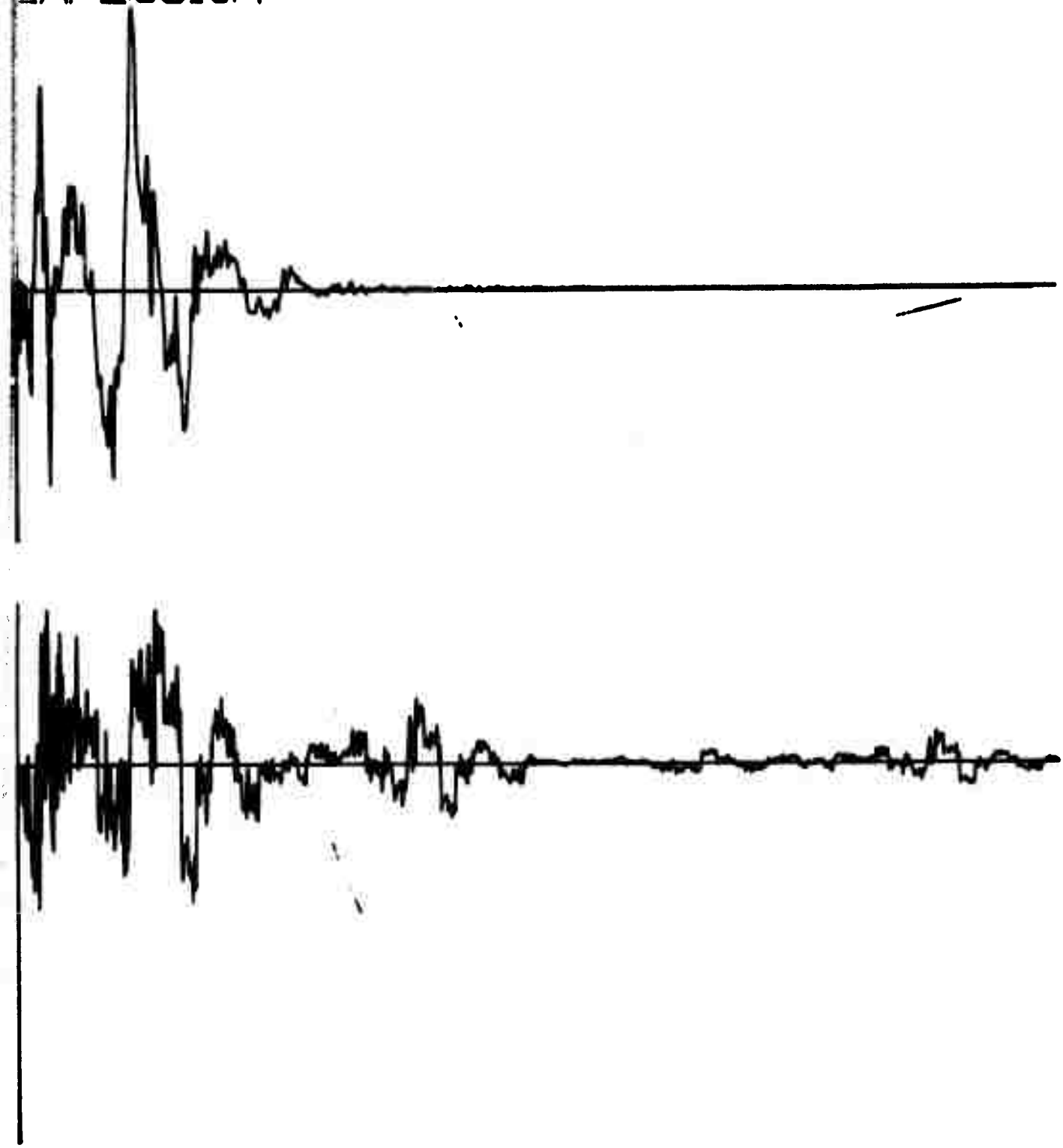
EVENT NUMBER 1332
EARTHQUAKE



VENT NUMBER 1327
ARTHQUAKE



EVENT NUMBER 1552
EXPLOSION



EVENT NUMBER 1550
EXPLOSION